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ON THE STRESSES OF RIGID ARCHES, CONTINUOUS BEAMS, AND CURVED STRUCTURES.

(*Continued from page* 201.)

EFFECT OF BENDING MOMENT, AND AMOUNT OF TOTAL STRESS.

In order to appreciate the effect of the addition of a bending moment on the stress of an arched rib, let F be the resultant pressure in the direction of the tangent to the curve of equilibrium, which may, for the purpose of this illustration, be supposed parallel to the tangent to the neutral line of the rib, or the uniform compressive force if the rib be in the state of the voussoir arch (Figs. A and B); and let p be the perpendicular let fall on the direction of F at the point of the rib to which F corresponds. The addition of two forces $+F'$ and $-F'$, each equal in amount to F, but acting in opposite directions, at that point of the neutral line of the rib to which F corresponds, the directions being coincident with the tangent to the neutral line, will not disturb the equilibrium; and F may be considered as equivalent to $+F, +F'$ and $-F'$. The effect of $+F$ and $-F'$ is to cause a bending moment, and, since $F'=F$, the effect of the remaining force $+F'$ is to cause a direct compression of the rib, of the same amount as if F acted in the neutral line. The bending moment

$$M = F\,p;$$

and if I is put equal to $A\,q^2$, where A is the area of cross section and q its radius of gyration in reference to the neutral axis, then by formula (2)

$$F\,p = \frac{t_0}{k_0} A\,q^2,$$

and

$$t_0' = \frac{F}{A} \cdot \frac{k_0\,p}{q^2}$$

for the tension or compression per square inch arising from the action of the bending moment, or what has been called the forces t and c in Figs. A and B.

The total stress being that due to the direct action of F and a couple represented by $F\,p$, the rib will sustain a direct compression from F as well as the force t_0. This compression, considered as uniformly distributed over the area A of section, will give a compression per square inch of $\frac{F}{A}$, and the total stress will be

$$\frac{F}{A} + \frac{F}{A} \cdot \frac{k_0\,p}{q^2};$$

or, since $\frac{F}{A}$ is what has been called the force f in Figs. A and B,

$$\text{Total stress} = f\left(1 + \frac{k_0\,p}{q^2}\right) \quad . \quad . \quad (6a)$$

the positive sign representing compression, and the negative sign tension.

If p be taken $= k_0$, that is, if a point in the arch rib be considered for which the curve of equilibrium is approximately coincident with the outer surface, the above value of the stress becomes

$$\left\{1 + \left(\frac{k_0}{q}\right)^2\right\}.$$

The value of $\frac{k_0}{q}$ depends on the form of cross section of the rib; but there are some

leading types of section for which this ratio is readily determined.

(1.) For a thin box or I-shaped girder $\left(\frac{k_0}{q}\right)^2$ may be taken as approximately $=1$, and the stress therefore will be $f\ (1+1)$ or $2f$; that is, the stress f is double at the point where the curve of equilibrium touches the outer surface of the rib, and writing $-k_0$ for $k_0 f\ (1-1)$, or zero, at the point in the opposite surface.

(2.) For a thin circular or elliptical tube, $\frac{k_0}{q}$ is nearly $=\sqrt{2}$, and $\left(\frac{k_0}{q}\right)^2$ nearly $=2$. For this form of section, therefore, the uniform stress is tripled at the point where the curve of equilibrium coincides with the outer surface of the rib, and there is a force $f\ (1-2)$ or $-f$ or a tensile force equal to f acting at the other surface of the rib.

(3.) For a solid rectangular form of cross section $\frac{k_0}{q}$ is equal to $\sqrt{3}$, and $\left(\frac{k_0}{q}\right)^2=3$, and for this form the uniform compressive force is quadrupled, at the one surface of the rib, and there is a tensile force of $f\ (1-3)$ or $2f$, at the other surface.

(4.) For a circular or elliptical solid bar, $\frac{k_0}{q}$ is equal to 2, and $\left(\frac{k_0}{q}\right)^2=4$. For this form the uniform compressive force is quintupled at one surface of the rib, and there is a tensile force of $f\ (1-4)$, or $3f$, at the other surface.

It will be obvious from these examples that the first-mentioned section is much better fitted for resisting this kind of stress than any of the others.

The general conditions of equilibrium having been explained, the action of vertical forces will be first examined.

FIG. E.

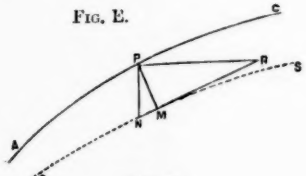


FIG F.

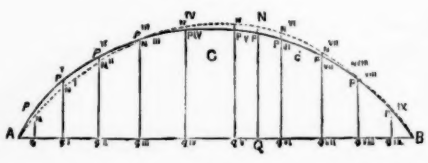
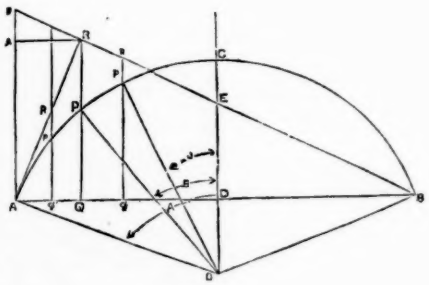


FIG. G.



VERTICAL FORCES.

If P, Fig. E, be any point in an arch rib of which the neutral line is A P C, the curve of equilibrium Q S, and P M the perpendicular let fall from P on the direction of the resultant, then the bending moment, as already explained, is

$$M = F \times P\,M.$$

Draw P N vertical, cutting the curve of equilibrium in N, R N tangential at this point N, and P M perpendicular to R N, also P R horizontal cutting R N in R.

Calling H the horizontal thrust,

$$F : H : : R\,N : R\,P;$$

and by similar triangles,

$$P\,M : R\,P : : P\,N : R\,N.$$

Combining these proportions,

$$F \times P\,M = H \times P\,N.$$

Or, since in the case of vertical pressures the value of H is uniform throughout the curve, the value of M is measured simply by the length of the vertical line P N between the neutral line of the rib and the curve of equilibrium.

The conditions of equations (3) and (6) are therefore simplified.

If the rib be considered as rigid, and the ends kept from spreading, the condition to be satisfied is (see Fig. F):

$$\Sigma\,(P\,N \times P\,Q) = 0.$$

If the rib is also "fixed" at A and B, the conditions are

$$\Sigma\,(P\,N) = 0$$
$$\Sigma\,(P\,N \times P\,Q) = 0.$$

The process of construction is therefore as follows (Fig. F):

Having divided the neutral line of the arch rib into equal portions, draw vertical lines through the centres, p, p', p'', etc., of the divisions, which will cut the base line, or line joining A and B, in the points q, q', q'', etc. Also draw an approximate curve of equilibrium, which will be cut by these verticals in the points n, n', n'', etc.

Then, if the rib be considered as rigid, with the points A and B kept from moving sideways, the curve of equilibrium must be such that between the points A and B,

$$p\,n \times p\,q + p'\,n' \times p'\,q' + p''\,n'' \times p''\,q'' + \text{etc.} = 0.$$

That is, those products where the point n is above p, as at n^{iv}, n^{v}, etc., must balance the products where n is below p, as at n, n^{i}, etc. By satisfying this condition, the bending moments which increase the curvature and span will exactly neutralize those which diminish the curvature and span, so that the span will be unaltered. It is not difficult to find the correct curve of equilibrium after a few trials. The values of $p\,n$ and $p\,q$ can be measured by scale from the diagram, and a sliding rule will be found useful in obtaining the products. In the figure, near the vertex, where the bending moments $p^{iv}\,n^{iv}$, etc., are multiplied by the larger lengths $p^{iv}\,q^{iv}$, these products are more effective in the summation than at the haunches, where the lengths $p\,q$ are shorter, and thus the area between the two curves for that part where the neutral line of the rib is above the curve of equilibrium will require to be smaller than for the part where it lies below.*

When the arch rib is also fixed in direction at A and B, the curve of equilibrium must be so taken that between these points, due regard being had to the signs,

$$p\,n + p'\,n' + p''\,n'' + p'''\,n''' + \text{etc.} \;\ldots = 0.$$

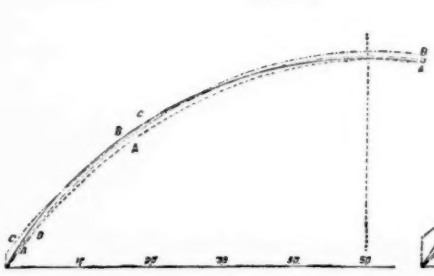
and

$$p\,n \times p\,q + p'\,n' \times p'\,q' + p''\,n'' \times p''\,q'' + \text{etc.} \;\ldots = 0.$$

Generally, in order to satisfy these two conditions, the springing points of the curve of equilibrium must be different from A and B, and will require to be shifted vertically.

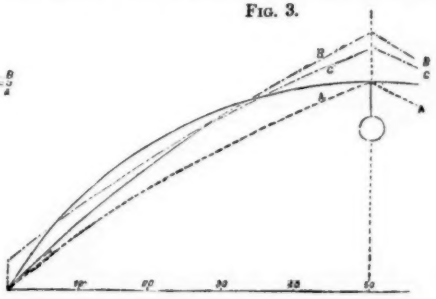
Roughly speaking, the first condition implies that the areas above and below the neutral line of the rib approximately balance one another. A curve being drawn which will nearly satisfy this condition, the curve can then be turned round the points midway between the point of its greatest separation from the neutral line of the rib and the ends A and B, until the second condition is also satisfied.

FIG. 2.



Segmental Arch unloaded.

FIG. 3.



Segmental Arch loaded in the middle.

Taking, for example, the circular rib of 120 deg. examined in Mr. W. Airy's treatise on "Iron Arches," the results from the method now explained may be compared with those arrived at by mathematical investigation.

Fig. 2 represents the rib acted on only by its own weight, considered as uniform per foot run of the rib; Fig. 3, where a

*Major Browne, R.E., has suggested that, in order to avoid drawing a number of trial curves, the curve of equilibrium may be made to pass accurately through any given point by the use of proportional compasses. Suppose the given point to be N′, above or below N, see Fig F; then, having drawn the trial curve which passes through N, the curve which passes through N′ will have the ordinate Q N altered in the ratio Q N′ : Q N; and since any other ordinate, as $q\,n$, will be altered in the same proportion, this may be done by setting the compasses to the ratio Q N′ : Q N; or, if straight lines A N, A N′ be drawn from A through N and N′, for any two points at the same level, one point on the straight line A N, and the other on the trial curve which passes through N, the distance between the lines A N, and A N′ measured vertically, is equal to the distance, also measured vertically, between the curve which passes through N, and that which will pass through N′.

load a little less than the weight of the rib, in the proportion of the chord of the arc of 60 deg. to the arc itself, acts at the centre of the crown; and Fig 4, where this weight acts at 30 deg. from the crown.

In these figures, the full line represents the line of the arch rib; the dotted line (a) corresponds to the curve of equilibrium of the voussoir arch, or rib hinged at the crown; the dotted line (b) to the rigid arch, with the ends kept from spreading; and the dotted line (c) to the rigid arch, with the ends "fixed."

In the following mathematical investigation of the voussoir arch, and arch with the ends fixed, the method used by Mr. W. Airy is adhered to as closely as possible, for the sake of comparison; and a short recapitulation of that method may be made for the better understanding of the case examined, namely, the rigid arch with the ends kept from spreading.

It is only necessary to investigate the case of the weight acting eccentrically, since by making the eccentricity equal zero, or the acting weight equal zero, this may be made to include the cases of the weight acting on the centre of the crown, or that of the heavy rib acted on by no additional weight.

Let the radius C O = R (Fig. G), and A O C, the semi-angle of the rib = a.

Supposing the weight W to act at the point P, let P O C = β, and let the weight of unity of length of the arch rib = ω, and let H and K be the horizontal and vertical forces acting at A, H being the horizontal thrust.

For any point p to the right of P, for which the angle C O $p = \theta$, the moment M of all the forces acting at p will be

M = weight of arc p A $\times$ horizontal distance of its centre of gravity from p + W $\times$ Q q + H $\times$ p q − K $\times$ A q.

If p be to the left of P, the term W $\times$ Q q in this value of M must be omitted.

To find the first term, θ being considered as a variable angle, the weight of an elementary portion of the arc R $d\theta$ is ω R $d\theta$, the horizontal distance of its centre of gravity from C is R sin θ, and the moment with respect to C is ω R^2 sin θ $d\theta$, the integral of which, for the arc C p between $\theta = 0$ and $\theta = \theta$, is ω R^2 (1 − cos θ).

In like manner, the moment of the arc C A with respect to C is ω R^2 (1 − cos a), and the moment of p A or the difference of these two, is ω R^2 (cos θ — cos a).

The horizontal distance of the centre of gravity of p A from C is therefore ω R ($a - \theta$) being the weight of p A.

$$\frac{\omega R^2 (\cos\theta - \cos a)}{\omega R (a-\theta)} \text{ or } R \cdot \frac{\cos\theta - \cos a}{a-\theta}$$

and its horizontal distance from p is

$$R \cdot \frac{\cos\theta - \cos a}{a-\theta} - R \sin\theta,$$

and the moment with respect to p,

$$\omega R (a-\theta \left\{ R \frac{\cos\theta - \cos a}{a-\theta} - R \sin\theta. \right\}$$

or,

$$\omega R^2 (\cos\theta - \cos a + \theta \sin\theta - a \sin\theta).$$

Also

$$Q\,q = R (\sin\beta - \sin\theta)$$
$$p\,q = R (\cos\theta - \cos a)$$
$$A\,q = R (\sin a - \sin\theta).$$

To find the upward pressure K, take moments with respect to B:

K $\times$ A B = W $\times$ Q B + weight of A C B $\times$ D B

or,

$$K R (2 \sin a) = W R (\sin a + \sin\beta) + \omega R\, 2a R \sin a.$$

$$K = \frac{W}{2} \cdot \frac{\sin a + \sin\beta}{\sin a} + \omega R a,$$

and the above value of M becomes, after reduction, as found by Mr. Airy,

$$\begin{aligned} M = {} & \omega R^2 (\cos\theta + \theta \sin\theta - \cos a - a \sin a) \\ & + W R (\sin\beta - \sin\theta). \\ & + H R (\cos\theta - \cos a) \quad . \quad . \quad . \quad (7.) \\ & + \frac{W}{2} R \cdot \frac{\sin a + \sin\beta}{\sin a} (\sin\theta \sin a), \end{aligned}$$

where it is to be observed that for a point to the left of P, the term W $\times$ Q q, or the term W R (sin β − sin θ), must be omitted between $\theta = +\beta$ and $\theta = +a$.

From the manner in which this value of M has been obtained, it will evidently have the same expression, whether the arch is considered as a voussoir arch or as a rigid arch with the ends kept from spreading, the difference between these two cases being that the value for H is different for each.

For the rigid arch with the ends fixed, there will be a bending moment μ for the present unknown, acting at A, and over the whole arch rib, until it is met and counteracted by the equal but opposite moment $-\mu$ acting at the point B. In this case, therefore, the bending moment at any point will be M + μ instead of M.

The unknown horizontal thrust H, which appears in the value of M, will now be determined.

For the voussoir arch, there being no bending moment or transverse stress at the crown, taking moments to the left of C with respect to that point :

Moment of the arc

$$C\,A+W\times Q\,D+H\times D\,C=K\times A\,D,$$

or,

$$\omega R^3(1-\cos\alpha)+W\times R\sin\beta+H\,R(1-\cos\alpha)=\left\{\frac{W}{2}\cdot\frac{\sin\alpha+\sin\beta}{\sin\alpha}+\omega R\,\alpha\right\}R\sin\alpha,$$

and reducing

$$H=\frac{W}{2}\cdot\frac{\sin\alpha-\sin\beta}{1-\cos\alpha}+\omega R\left(\frac{\alpha\sin\alpha}{1-\cos\alpha}-1\right) \quad (8.)$$

In the case of the rigid arch with the ends kept from spreading, the condition of equation (6) must be satisfied, or

$$\Sigma\,(M\times P\,Q)=0$$

$$\Delta s=R\,\Delta\theta$$

and since

$$\int_{-\alpha}^{+\alpha}M.R(\cos\theta-\cos\alpha)\,R\,d\theta=0.$$

Bearing in mind the omission of the term $W\,R(\sin\beta-\sin\theta)$ between $+\beta$ and $+\alpha$ in the integration, the resulting value of H, as given in Mr. Airy's treatise, is

$$H=\omega R\,\frac{\alpha^2\sin\alpha\cos\alpha+\alpha(\frac{3}{4}\cos^2\alpha-\frac{1}{4}\sin^2\alpha)-\frac{9}{4}\sin\alpha\cos\alpha}{\frac{3}{2}\sin\alpha\cos\alpha-\alpha(\frac{1}{2}\sin^2\alpha+\frac{3}{2}\cos^2\alpha)}$$

$$+\frac{W}{2}\cdot\frac{\frac{3}{2}\cos^2\alpha-\frac{1}{2}\cos^2\beta-\cos\alpha\cos\beta+(\alpha\sin\alpha-\beta\sin\beta)\cos\alpha}{\frac{3}{2}\sin\alpha\cos\alpha-\alpha(\frac{1}{2}\sin^2\alpha+\frac{3}{2}\cos^2\alpha}. \quad (9.)$$

For the rigid arch with the ends fixed, both in direction and position, $M+\mu$ must be substituted for M in the above integration, which changes it to

$$\int_{-\alpha}^{+\alpha}M(\cos\theta-\cos\alpha)\,d\theta+\int_{-\alpha}^{+\alpha}\mu(\cos\theta-\cos\alpha)\,d\theta=0,$$

Integrating,

$$0=\omega R^2\left\{-\frac{9}{4}\sin\alpha\cos\alpha+\alpha(\frac{3}{2}\cos^2\alpha-\frac{1}{2}\sin^2\alpha)+\alpha^2.2\sin\alpha\cos\alpha\right\}$$

$$+WR\left\{\frac{3}{2}\cos^2\alpha-\frac{1}{2}\cos^2\beta-\cos\alpha\cos\beta+(\alpha\sin\alpha-\beta\sin\beta)\cos\alpha\right\} \quad (10.)$$

$$+HR\left\{\alpha(\sin^2\alpha+3\cos^2\alpha)-3\sin\alpha\cos\alpha\right\}$$

$$+\mu.2(\sin\alpha-\alpha\cos\alpha).$$

In this case the condition of equation (3) is also to be satisfied, or,

$$\int_{-\alpha}^{+\alpha}M\,R\,d\theta=0.$$

Substituting in this the value of M from equation (7), integrating between the limits $-\alpha$ and $+\alpha$, omitting the term $W\,R\,(\sin\beta-\sin\theta)$ between $+\beta$ and $+\alpha$ and reducing,

$$0=\omega R^2\left\{2\left(\frac{\sin\alpha}{\alpha}-\cos\alpha\right)-\alpha\sin\alpha\right\}$$

$$+\frac{W}{2}R\left\{\frac{\cos\beta}{\alpha}-\frac{\cos\alpha}{\alpha}+\frac{\beta}{\alpha}\sin\beta-\sin\alpha\right\} \quad (11.)$$

$$+HR\left\{\frac{\sin\alpha}{\alpha}-\cos\alpha\right\}$$

$$+\mu.$$

From (8) and (9) the values of H being determined and substituted in (7), the bending moment M at any point of the voussoir and rigid arch with the ends kept from spreading may be found; and in like manner from (10) and (11) the values of H and μ may be determined, and the resulting value of $M+\mu$ from (7), will give the bending moment at any point of the rigid arch with the ends fixed.

For $\alpha=60°$. $\beta=0°$.

Equation (8) becomes

$$H=.866\,W+.814\,\omega\,R,$$

and equation (9),

$$H=.631\,W+.787\,\omega\,R;$$

also equations 10 and 11 become

$$0=-.172\,W\,R-.213\,\omega\,R^2+.272\,H\,R+.685\mu$$
$$0=-.195\,W\,R-.253\,\omega\,R^2+.327\,H\,R+\mu,$$

giving

$$H=.805\,W+.841\,\omega\,R$$
$$\mu=-.022\,\omega\,R^2-.069\,W\,R.$$

In like manner, for $\alpha=60°$, $\beta=30°$, equation (8) becomes

$$H=.366\,W+.814\,\omega\,R,$$

and equation (9)

$$H=.406\,W+.787\,\omega\,R;$$

Equations (10) and (11) become

$$0=-.110\,W\,R-.213\,\omega\,R^2+.272\,H\,R+.685\,\mu$$
$$0=-.133\,W\,R-.253\,\omega\,R^2+.327\,H\,R+\mu,$$

giving

$$H=.401\,W+.841\,\omega\,R$$
$$\mu=-.022\,\omega\,R^2+.002\,W\,R.$$

To compare the bending moments with those derived from Figs. 2, 3, and 4, since

$$M=H\times P\,N\ (\text{Fig. F})$$

$$P\,N=\frac{M}{H},$$

or, in the case of the arch with the ends fixed in direction,

$$P\,N=\frac{M+\mu}{H}$$

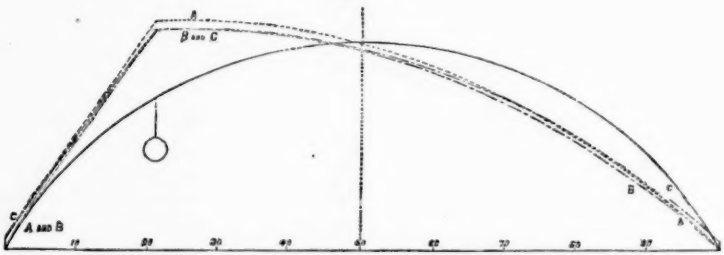
Now, if the values of P N be calculated from these equations, it will be found that they can, for all practical purposes, be equally well ascertained by scaling their equivalents P N from Figs. 2, 3, and 4.

Before parting with the above formulæ, an examination of them shows that the expressions for H and M, or M+μ, are the algebraical sums of two parts, one corresponding to ω=0, and the other to W=0.

It follows from this, that if at any point the stress, which is proportional to the bending moment, caused by the weight of the rib itself, or rib and its fixed loading, be found, and also that caused by a moving load acting on the point, the total stress is obtained by adding these two stresses together with their proper signs.

As the action of a moving load can thus be separated from the action of a fixed load,

FIG. 4.

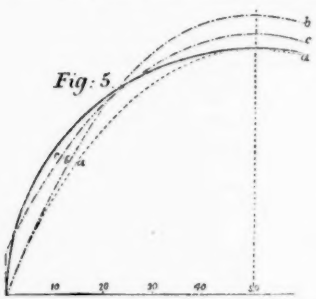


Segmental Arch under its own Weight and a load on the haunch.

it may be useful to examine the cases of a circular rib of 120 deg., and of a semi-circular arch rib.

ACTION OF THE WEIGHT OF THE ARCH.

Figs. 2 and 5 show the stresses arising from the weight of the arch itself considered as the fixed load. The vertex and springing points were determined by the above formulæ, and the curves of equilibri-



Semicircular Arch, unloaded.

um drawn to pass through these points. Calling P the weight of the semi-arch, and R its radius, the value of H, $\frac{M}{H}$ when θ=0, and of $\frac{\mu}{H}$ are given in the following table.

Voussoir arch

	For $\alpha = 60°$	For $\alpha = 90°$
H	= .777 P	H = .363 P

Rigid arch—ends kept from spreading;

H	= .751 P	H	= .318 P
$\frac{M_{\theta=0}}{H}$	= −.018 R	$\frac{M_{\theta=0}}{H}$	= −.142 R

Rigid arch with the ends fixed:

H	= .803 P	H	= .407 P
$\frac{M_{\theta=0}}{H}$	= −.009 R	$\frac{M_{\theta=0}}{H}$	= −.171 R
$\frac{\mu}{H}$	= −.026 R	$\frac{\mu}{H}$	= −.064 R

By these values of $\frac{M}{H}$ when $\theta = 0$, and of $\frac{\mu}{H}$, the vertices and springing points of the curves were determined. It will be observed that the stresses on the rigid arch are in both cases reduced to about one-half by fixing the ends.

The curves of equilibrium for a moving load will now be considered.

ACTION OF A MOVING LOAD.

If the load on a particular point of the arch be the only force acting, since there are then no forces to bend the curve of equilibrium, it becomes two straight lines, meeting in an apex vertically above the load. For the voussoir arch and rigid arch of invariable span, these lines pass through the centre of the ends of the arch rib.

That the bending moments are measured

by the vertical ordinates between these lines of equilibrium and the curve of the rib may be shown as follows:

Putting $\omega = 0$ in equation (7), the value of $\frac{M}{H}$ after reduction is

$$\frac{M}{H} = R\left\{\cos\theta - \cos\alpha - \tfrac{1}{2}\frac{W}{H}\cdot\frac{\sin\alpha+\sin\theta}{\sin\alpha}(\sin\alpha-\sin\beta)\right\} \quad (12.)$$

If P (Fig. G) be the position of the weight, draw the vertical lines Q P R and Ab through P and A, and the horizontal line R a through R, an assumed apex or intersection of the lines of equilibrium R A, R B.

Then

$$W : H :: A\,b : a\,R$$

But

$$a\,R = Q\,A = R(\sin\alpha - \sin\beta).$$

Therefore

$$A\,b = R\frac{W}{H}(\sin\alpha - \sin\beta).$$

Also

$$B\,D : E\,D :: B\,Q : Q\,R,$$

or,

$$Q\,R = E\,D.\frac{B\,Q}{B\,D} = E\,D.\frac{R(\sin\alpha+\sin\beta)}{R\sin\alpha}$$

and

$$= \frac{R}{2}\frac{W}{H}(\sin\alpha - \sin\beta)\frac{\sin\alpha+\sin\beta}{\sin\alpha},$$

and

$$P\,R = Q\,R - Q\,P$$

$$= \frac{R}{2}\frac{W}{H}\cdot\frac{\sin\alpha+\sin\beta}{\sin\alpha}(\sin\alpha-\sin\beta) - R(\cos\beta-\cos\alpha);$$

the same as the above value of $\frac{M}{H}$ when $\theta = \beta$, but with an opposite sign, since M has been treated as negative when R is above P.

Then if p be a point to the right of P, for which the angle $p\,O\,C = \theta$,

$$B\,Q : B\,q :: Q\,R : q\,r,$$

and

$$q\,r = Q\,R\,\frac{B\,q}{B\,Q} = \tfrac{1}{2}\frac{W}{H}R\frac{\sin\alpha+\sin\beta}{\sin\alpha}(\sin\alpha-\sin\beta)\frac{\sin\alpha+\sin\theta}{\sin\alpha+\sin\beta}$$

$$= \tfrac{1}{2}\frac{W}{H}R.\frac{\sin\alpha+\sin\theta}{\sin\alpha}(\sin\alpha-\sin\beta),$$

and

$$p\,r = q\,r - q\,p$$

$$= \tfrac{1}{2}\frac{W}{H}R.\frac{\sin\alpha+\sin\theta}{\sin\alpha}(\sin\alpha-\sin\beta) - R(\cos\theta-\cos\alpha);$$

the same as the general value of $\frac{M}{H}$ in (12), but with a negative sign as already explained.

For a point to the left of P, the term W R $(\sin\beta - \sin\theta)$ being omitted in the value of M, equation (7) gives

$$\frac{M}{H} = R(\cos\theta - \cos\alpha + \tfrac{1}{2}\frac{W}{H}R\frac{\sin\alpha+\sin\beta}{\sin\alpha}(\sin\theta-\sin\alpha),$$

and from Fig. G,

$$A\,Q : A\,q' :: Q\,R : q'\,r'$$

$$q'r' = Q\,R\,\frac{A\,q'}{A\,Q} = Q\,R.\frac{\sin\alpha-\sin\theta}{\sin\alpha-\sin\beta}$$

$$= \tfrac{1}{2}\frac{W}{H}R.\frac{\sin\alpha+\sin\beta}{\sin\alpha}(\sin\alpha-\sin\theta),$$

and

$$p'r' = q'r' - q'p'$$

$$= \tfrac{1}{2}\frac{W}{H}R.\frac{\sin\alpha+\sin\beta}{\sin\alpha}(\sin\alpha-\sin\theta) - R\cos\theta-\cos\alpha),$$

the same as the above value of $\frac{M}{H}$, but with the negative sign.

For the voussoir arch, since there is no bending moment at the crown, one of the lines of equilibrium is fixed by the condition that it must pass through the crown, and through the end of the arch farthest from the load; the other line is fixed by making it pass through the end of the arch nearest the load, and the point where a vertical line through the load cuts the first-mentioned line.

For the rigid arch, a curve line above the arch can be found, such that, for any given position of the load, the vertical line through the load will intersect this curve in a point, which point will be the apex of the two lines of equilibrium for that position of the load.

To draw this curve, or locus of the apex, it is only necessary to find from (12) the value of $\frac{M}{H}$ when $\theta = \beta$, and lay off above the point where the weight acts a vertical length equal to this. By finding a sufficient number of points the curve can be drawn.

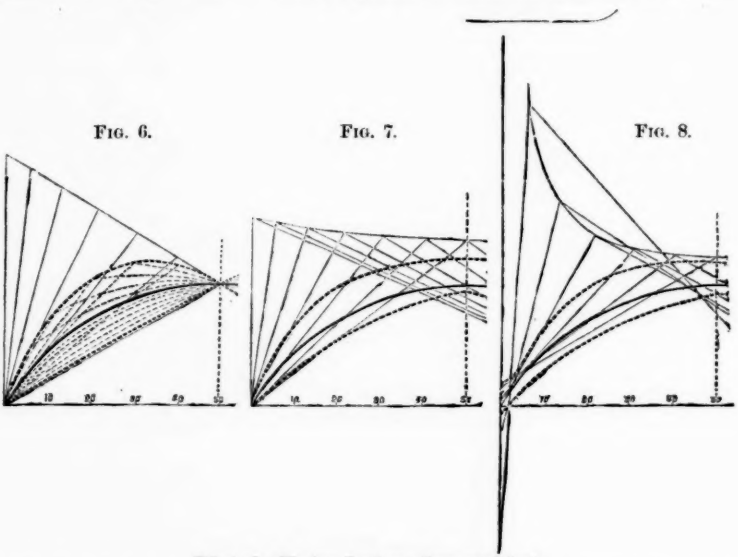
Figs. 7 to 10 show the lines of equilibrium, and the locus of the apex for the arc of 120 deg., and for the semicircular arc. For the latter, the locus becomes a straight line, drawn at a distance of $\frac{\pi}{2}$ R above the centre of the circle, or its height above this centre is equal to the length of the quadrant.

On Figs. 8 and 11, for the rigid arch with

the ends fixed, the lines of equilibrium are shown for different positions of the load, the springing points of these lines being determined by the values of $\frac{\mu}{H}$ from (10) and (11).

Where so many lines were to be found, it was easier to fix their points of intersection by formulæ already obtained than to find each by a separate graphic construction. The lines are in the same positions as would have been found by construction, the lines of equilibrium on Figs. 7 and 10 satisfying Eq. (6), and those on Figs. 8 and 11, Equations (3) and (6).

But the lines on these Figs. only serve to compare among themselves the stresses on different points of the rib for the same position of the load. The bending moment being compounded of the horizontal thrust, as well as the height P N (Fig. F), it is necessary, in order to compare the absolute stresses for different positions of the load, to take into account the change of horizontal thrust. This comparison may be made by



Effect of a Moving Load on a Segmental Arch.

Fig. 6.—Voussoir Arch. Fig. 7.—Rigid Arch, ends free. Fig. 8.—Rigid Arch, ends fixed.

arranging that all the stresses may contain a common factor, and the simplest common factor is the weight itself. The bending moment, or H $\times$ P N, may then be assumed equal to W $\times$ x, giving,

$$x = \frac{H}{W} \cdot P\,N.$$

That is, by plotting at the different points of the rib, heights or depths less than P N in the ratio of H to W, these new heights being multiplied by W, will give the bending moments.

In this manner, the network of lines on Fig. 6 has been drawn, and the dotted lines which are passed through the points of maximum bending moment, show the greatest stresses to which the rib is exposed during the passage of a load from one side to the other of the arch rib. It will be observed that the greatest stress occurs when the load is about midway between the crown of the arch and the abutment.

On Figs. 7 to 11, only the dotted lines of maximum bending moment have been drawn. This maximum bending moment is equal to the weight multiplied by the vertical distance between the neutral line of the arch rib, and the dotted line, to the same scale as the arch rib is drawn. For example, in a semicircular rigid arch, of 100 ft. span, with the ends kept from spreading, the greatest bending moment for a weight of 10 tons passing along it occurs when the weight is over the centre of the rib, and is measured by 10 tons $\times$ 9 ft. tending to les-

sen the curvature; and during the passage of the load there is at a point 50 deg. from the crown a bending moment of 10 tons $\times$ 5 ft. 3 in. tending to increase the curvature.

Putting k for the length of the line P M (Fig. F).

$$M = H\,k,$$

and denoting by M′, H′, and k', similar quantities corresponding to a weight W′, in like manner,

$$M' = H'\,k'$$

and

$$M + M' = H\,k + H'\,k'.$$

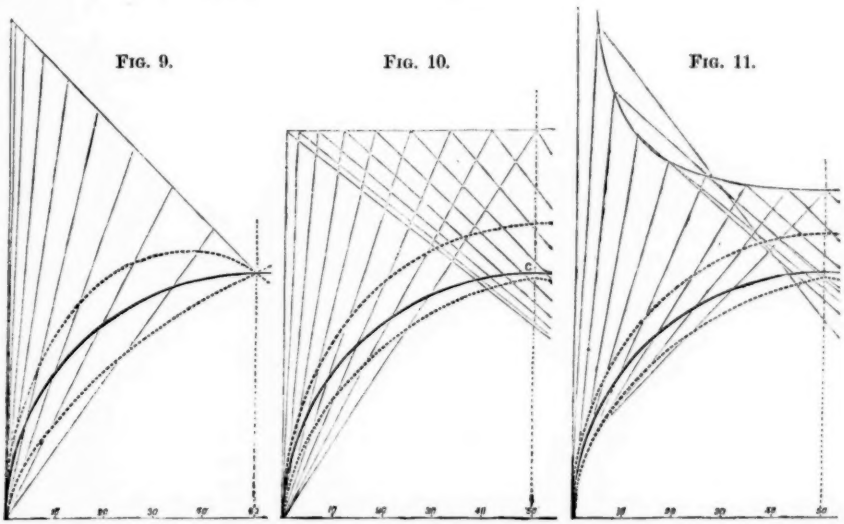
But the horizontal thrust for W and W′ acting together will be H+H′. Let, therefore,

$$(H + H')\,k'' = H\,k + H'\,k'.$$

Then

$$k'' = k \cdot \frac{H}{H+H'} + k' \cdot \frac{H'}{H+H'} \quad . \quad . \quad (13.)$$

or the length P N for the combined curve may be found by adding together the lengths for W and W′, each reduced in the ratio of its horizontal thrust to the total horizontal thrust. An example of this is given in the voussoir arch first examined.



Effect of a Moving Load on a Semicircular Arch.

ACTION OF A UNIFORMLY DISTRIBUTED LOAD.

Since the values of H and M are proportional to W, the stress caused by any number of weights is the sum of the stresses caused by each separately, and Figs. 6 to 11 give the means of ascertaining the position and amount of greatest stress for a uniform load, supposed to be put on the arch beginning from one end, until the whole is covered.

But the action of a uniform load on a definite part or the whole of an arch can be arrived at with greater facility by the constructive method of drawing the curves of equilibrium. Examples of this for the rigid arch, with the ends kept from spreading, are given on Figs. 12, 13, and 14. Fig. 12 represents an arch whose rise is $\frac{1}{10}$ of the span. One of the dotted lines (*b*) shows the curve of equilibrium when a moving load, equal per foot run to $\frac{1}{2}$ the fixed load, has a uniform horizontal distribution over one-half of the arch in its central part; and the other dotted line (*c*) shows the curve when the uniform horizontal distribution of the moving load is over the half of the arch from the centre to the abutment.

Fig. 13 represents the arch of 120 deg. already examined. The dotted line (*a*) is the curve, a parabola, for the rigid arch with the span invariable, under a uniform horizontal loading all over. The dotted line (*b*) shows the curve when a moving load, equal to $\frac{1}{2}$ the fixed load per foot run, ex-

tends over $\frac{1}{4}$ of the span each way from the centre, or over $\frac{1}{2}$ the span altogether, the dotted line (*c*), when the same moving load extends from the centre to one of the abutments.

For the sake of comparison with the last, Fig. 14 shows the curves of the rigid arch of invariable span, the form of the arch being not circular but parabolic. The parabola is the curve of equilibrium for a uniform horizontal load, so that when the loading is distributed all over the span, the curve of equilibrium coincides with the curve of the arch rib, and there is no transverse stress. The dotted line (*b*) shows the curve with the above-mentioned moving load extending over $\frac{1}{2}$ of the span each way from the centre; the dotted line (*c*) shows the curve when the moving load extends from the centre to one of the abutments.

The loading being supposed uniform horizontally, the weight which acts at each of the verticals is proportional to the horizontal projection of the division of the arc which it bisects. From these weights the curves of equilibrium have been constructed so as to satisfy equation (6).

It will be observed that when the moving load extends from the centre to the abutment, although the transverse stress tending to diminish the curvature of the arch at its loaded part is considerable, there is an equal, and in the case of the arc of 120 deg., a rather greater transverse stress at the unloaded haunch tending to increase the curvature. Since the inequality of the loading may act on the opposite side of the arch, the curves may be transferred from one side to the other, and the stresses reversed. When the moving load acts on $\frac{1}{4}$ of the span each way from the centre, the transverse stress tending to increase the curvature at the haunches is rather greater than the stress of the opposite kind at the centre of the arch.

The curves for the parabolic rib show rather less stresses for partial loading than those for the circular rib, so that the former, which has no transverse stress when the load is uniformly distributed over it horizontally, has a slight advantage over the circular rib in the event of unequal loading. As the rise of the arch is diminished, the circular and parabolic curves come so close together as to be practically the same.

STRAIGHT OR CURVED GIRDER.

Putting m for the bending moment of all the vertical forces, the value of M in Eq. (7) —Fig. G—may be written

$$M = m + H.PQ.$$

This quantity m, or the sum of all those terms which do not contain H, is nothing else than the bending moment, supposing the arch were a girder.

If the arch becomes a girder, and

$$M = m,$$

then

$$H = 0;$$

and as already remarked, the ordinates of the curve of equilibrium are infinite.

But (Fig. F) bearing in mind that M is negative at the point P,

$$M = -H\ PN = m + H.PQ.$$

and

$$-m = H\ (PQ + PN) = H\ NQ.$$

That is H. N Q is the graphic representation of the bending moment of a girder of the same shape and loading as the arch. Since N Q is the vertical distance between the curve of equilibrium and the straight line, the bending moment is independent of the shape of the arch, which may be either curved or straight.

A straight or curved girder, then, may be considered as an arch of any rise, but without horizontal thrust; and if its length be divided into parts, and any curve of equilibrium drawn for the weights, continuous or discontinuous, acting on these parts, the stress at any point P will be represented by the value of H. N Q. Since H, varies inversely as N Q, H. N Q will be the same for all the curves of equilibrium that can be drawn. This remark leads to the following method of ascertaining the stresses on a continuous beam.

CONTINUOUS BEAM.

While examining, in the year 1849, the stresses on continuous beams for the late Mr. Brunel, in reference to the large bridge at Chepstow, the lower girder of which is virtually a continuous beam of five unequal spans, the Author, using the method of Navier, found the subject one of no inconsiderable difficulty, from the number and complexity of the eliminations required; and he was gratified by the formulæ at which he then arrived for beams up to five spans, being completely verified by the experimental tests to which he subjected

them, and which were devised by Mr. Brunel. One of these experiments is described in Mr. Edwin Clark's work on the Britannia Bridge.*

Since that time, the discovery of the "theorem of three moments" † has introduced great simplicity in the consideration of continuous beams of uniform section; and recently Mr. Heppel, in a Paper read before the Royal Society of London,‡ has been the first to solve the general problem of the continuous beam of varying section, and of any number of spans or manner of loading. The solution depends on certain definite integrals, which if they cannot always be obtained in a finite form, may, by the method of quadratures, be approximated to with as great numerical accuracy as may be desired.

Aware of the difficulty of the subject, the Author ventures to present it under a somewhat different aspect, and hopes to show, in the following remarks, that the stresses on a continuous beam of varying or uniform section may be ascertained with sufficient accuracy for practical purposes by a modification of the method of finding the stresses on rigid arches.

It will be convenient in the first instance to consider beams of uniform section.

For these, though loaded in any manner whatever, if they are supposed disconnected at the piers, a curve of equilibrium for each span may be drawn, the rise of the curve being arbitrary. And all the forces being vertical, the bending moment or stress at any point (see p. 38) would be measured by the horizontal thrust, multiplied by the vertical ordinate.

The condition that the sum of the upward pressures at the points of support must be equal to the downward pressures of the weights, would be complied with, since the weight acting on each span would be borne by the end supports.

When the beams are supposed to be connected together, so as to form one continuous beam extending over the whole of the spans, the above condition must still be satisfied; but, in consequence of the continuity, the weights borne by the different points of support will not be the same as when the beams are unconnected, and the differences will introduce bending moments at the points of support, and at every point of the beam, except at the two ends, where the bending moments are zero, unless external forces act on the beam at these points.

On the diagrams of the curves of equilibrium, the bending moments at the piers may be represented by vertical straight lines, each being the bending moment divided by the horizontal thrust.

On Fig. H, A C B and B E D being curves of equilibrium, for the weights acting on the spans A B, and B D, B x and D y represent the bending moments at B and D, and the stress at any point t, due to the alteration of pressure at the points of support caused by the continuity, will be represented by a vertical ordinate $t\,s$, from the straight line A B D to the straight lines A x, $x\,y$; and the actual stresses at any point t of the beam supposed continuous is represented by the difference between the ordinate of the curve and of the straight line, and is therefore equal to the horizontal thrust multiplied by $r\,s$.

And because, for any one pier, the bending moment there must be the same, whether moments are reckoned to the right or left, the horizontal thrust on one side, which requires to be multiplied by the length of the vertical line already mentioned to give the bending moment, must be equal to the horizontal thrust on the other side; that is, the horizontal thrust of two adjoining curves must be the same; and since the thrust is also constant throughout the same curve, it follows that in order to have a set of curves, the ordinates of which will represent the stresses on a continuous beam, it is necessary that the horizontal thrusts for the different spans should be all equal to one another, or the arches which these curves represent should be balanced arches. One curve being drawn, all the others are determined by this condition.

Commencing at one end A of the beam, (Fig. H.), draw the curve of equilibrium A C B for the weights acting on the span A B, of any convenient rise C G, measured on the same scale as that for the span A B, and call H the horizontal thrust of this curve.

To draw the curve for the next span, dividing the length B D in the middle, or any other convenient point m, let P P′ and Q Q′ be the vertical lines passing through the centres of gravity of the sums P and Q of the weights which act between m and B

* *Vide* Britannia and Conway Tubular Bridges, vol. i., p. 462.
† *Vide* Minutes of Proceedings Inst. C.E., vol. xxix., pp. 44—48.
‡ *Vide* Proceedings of the Royal Society of London, vol. xix., p. 56.

and m and D. From the positions of these weights, the vertical reactions at B and D may be found, the beam being at present not supposed to be continuous. Making B a equal to H, and $a\ b$ equal to the upward reaction at B, the line B b will be tangential to the curve of equilibrium at the point B, and will cut the vertical line P P′ in the point P′. Similarly the tangent at D may be found, and this will cut the vertical line Q Q′ in the point Q′. Joining P′ and Q′, the line P′ Q′ will be tangential to the curve of equilibrium at the point E in the vertical line E m, and the rise of the curve B E D will thus be determined. The curve for the span B D may then be drawn, and so on for the other spans.

Having thus drawn, on the horizontal line passing through the points of support, a series of curves of uniform horizontal thrust for the different spans, divide the whole length of the beam into any convenient number of equal parts, and draw vertical lines $t_0\ r_0$, $t_1\ r_1$, etc., through the centres of these divisions. If B x, D y, etc., be drawn tentatively to represent the bending moments at B, D, etc., caused by the altered pressures on the piers, the ordinates $s_0\ r_0$, $s_1\ r^0$, etc., will represent tentatively the stresses on the beam. And if a curve A K_0 B_1 K_1 D_1 F_1, etc., be drawn in such manner that at any point t the ordinate $t\ u$ is the algebraical sum, to any convenient scale, of all the ordinates $r_0 s_0$, $r_1 s_1$, etc., from A up to t, $t\ u$, will represent the area A C $r\ s$, or the change of angle of the elastic curve of the beam between A and t. Drawing, then, through this curve, and for the first span, a line $A_0\ B_0$ parallel to A B, so as to make the area A $A_0 K_0$ equal to the area $B_1 B_0$, the line A A_0 will represent the constant to be added in the integration to make these areas equal, or the ordinate of the elastic curve equal to zero at the point B; since this ordinate is represented by the sums of the ordinates or the area of this derived curve.

By the addition of the constant, the axis is shifted from A B to $A_0\ B_0$; and since the slope of the beam at the point B for the part A B must be the same as for the part B D, the curve B_1 K_1 D_1 for the second span must have the same ordinate $B_0\ B_1$ at B as that of the curve of the first span. That is, the axis of the curve for the second span lies in the prolongation of the axis for the first span. The same condition of equality of areas subsists, or the area $B_1\ B_0\ K_1$ must be equal to the area $D_0\ D_1\ K_1$. Similar remarks apply to the remaining spans.

In order, therefore, to ascertain the stresses on a continuous beam of uniform section, the primary curves of equilibrium must have the same horizontal thrust, and the derived curve A K_0 B_1 K_1, etc., must be capable of being cut by a line parallel to A B, in such manner that the areas above and below this line, for each span, shall balance one another. The heights B x D y, are to be arranged so that this condition is satisfied.

Fig. H is an example of the solution of the case of a continuous beam of three unequal spans, the conditions of each of which are purposely made as dissimilar to those of the others as possible. The lengths, A B, B D, and D F, have been assumed in the proportions of 4, 2, and 1; A B has been supposed loaded with a weight of 4, B D with a weight of 1, distributed over the span uniformly, and D F has been supposed unloaded.

The Author's diagrams of the curves of bending moment (Plate 12A, p. 190, vol. xxxii., Minutes of Proceedings Inst. C.E.) may be referred to as showing the lengths of the lines B x, D y, etc., under different conditions. These curves were constructed from the algebraical equations, but they are also true curves of equilibrium, with the springing points at different levels, for the insistent weights on the different spans. Curves corresponding to these for Fig. H are indicated by the dotted lines A C′ x' E′ y'. These curves may be derived from A C B E D by making B $x' =$ B x, D y, $=$ D y' and erecting on the sloping lines A x', x' y', vertical ordinates equal to the ordinates of the curves A C B E D measured from the horizontal line A B D. That is, for any point t, the line $r\ t$ being produced, to cut A x' in t' the vertical height $t'\ r'$ is made equal to $t\ r$. The bending moment at any point is thus equally represented by the line $r\ s$ of the curve A C B E D, or by the line $r'\ t$ of the curve A C′ x' E′ y'. The reason for constructing the curves of equilibrium on the horizontal lines A B, B D, etc., instead of on the sloping lines A x', etc., is that the sums of the ordinates, or areas of the curve of moments can then readily be found for any positions of the points, x, y, etc.; while, if these areas had to be obtained from curves drawn on the sloping lines, new curves of equilibrium would be required for

each different position of the points, x, y, etc.

The lengths B x, D y, etc., may be approximated to by assuming the beam to be severed at the ends of the several spans, beginning with the second. For the beam supposed continuous over the first two spans only, D y = zero, and the length B x can be readily found by balancing the areas of the derived curve A m n D_2, as already explained. If the beam be then supposed continuous over the first three spans, B x and D y may be determined after one or two trials by balancing the areas, and it will generally be found that B x will only differ slightly from the value already found for the continuous beam of two spans. Another span having been added, or the beam being supposed continuous over four spans, B x will scarcely require alteration, while D y will only require to be altered slightly. This process may be continued for any number of spans, and for any manner of loading. An examination of the curves on the Plate 12A already referred to shows, that the effect of loading any span is scarcely felt beyond the third or fourth span from the one loaded. In Fig H, the dotted line A m n D_2 is the derived curve for the beam supposed continuous over the first two spans only, and B x_2 is the corresponding bending moment at B, which in this case requires to be altered by the quantity x x_2 to suit the assumption of continuity over three spans instead of two.

The appropriate lines, A x, x y, etc., having been determined, the points of contrary flexure and of greatest bending moment can be ascertained by inspection of the diagram.

The slope and ordinate of the elastic curve of the beam at any point may also be found as follows:

Calling λ the vertical ordinate r s between the curve of equilibrium and the lines A x, x, y, etc., measured by the same scale as the spans A B, B D, etc., the bending moment M is equivalent to H λ, and the equation of equilibrium is

$$E\,I\,\frac{\Delta^2 y}{\Delta x^2} = H\,\lambda;$$

x being put for the abscissa A, t and y for the ordinate of the elastic curve of the beam, + x measured from A towards B, and + y measured downwards.

Hence

$$E\,I.\,\frac{\Delta y}{\Delta x} = H\left\{\Sigma\,(\lambda.\,\Delta x) + C\right\}$$

$$= H.\Delta x\left(\Sigma\,(\lambda) + \frac{C}{\Delta x}\right)$$

But by the construction $\Sigma\,(\lambda)$ is represented by the ordinate t u of the curve A K_0 B_1, etc., and AA_0 represents the arbitrary constant or $\frac{C}{\Delta x}$, in this case negative; v u is therefore equal to $\Sigma\,(\lambda) + \frac{C}{\Delta x}$ and if v u be put equal to ν,

$$\frac{\Delta y}{\Delta x} = \frac{H.x}{E.I}\,\nu,$$

an equation which gives the slope of the elastic curve of the beam at any point.

And for the ordinate of the elastic curve

$$y = \frac{H\,(\Delta x)^2}{E.I}\,\Sigma\,(\nu);$$

it being assumed that y=0 when x=0, or that the summation is commenced from the point A.

In reference to the above process it should be remarked that by making t u equal, on the appropriate scale, to the sum of all the ordinates r s, from A up to and inclusive of r s, t u thus really represents the sum of the heights of elementary parallelograms, or area A C r s divided by Δ x, not up to r s, but up to a vertical line half-way between r s and the next line of division further from A.

If the number of parts into which A B, etc., is divided be considerable, the inaccuracy is slight; in order to be quite accurate, the ordinate t u should be plotted half a division further from A than the ordinate r s, and t u will then represent the area of the curve A C r s up to a point of the beam, corresponding to the point u of the curve A K_0 B_1, etc. A similar remark applies to the ordinates v u of the curve A K_0 B_1, the sum of which represents, on the appropriate scale, the ordinate of the elastic curve; this sum up to any point t should be equal to the area contained between the straight line A_0 B_1 D_2, etc., and the curve A K_0 B_1 from A up to the point t. A correction like that above described may be applied here, but as small errors are cumulative in integrating twice, it will be more accurate to measure by scale the ordinates of the curve A K_0 B_1, etc., and enter these measurements in the summation which expresses the ordinates of the elastic curve.

For any of the spans acted on only by a definite load at a given point, the curve of

equilibrium is two straight lines as explained (p. 86), the horizontal thrust being the same as for the other spans.

If some of the spans are unloaded, as the span D F, Fig. H, the curve of equilibrium for one of these spans is a straight line D F joining the points of support; this line may be considered as representing a strut without weight, which conveys the horizontal thrust across the span, and vertical lines upwards or downwards, as may be necessary, will require to be drawn as before, in order to construct the derived curve and balance the areas.

If one or more of the points of support is not at the same level, and the continuous beam originally straight, the balancing of the areas will require to be arranged so that at the point corresponding to the support which is out of level a small overplus may be left equal to the appropriate area which will represent the amount of difference of level. If y in the above formula be put equal to this difference of level $(\Delta x)^2 \Sigma (\nu)$ will be the overplus of area.

To adapt the method to a continuous beam of varying section, it is only necessary in constructing the derived curve A K_0 B_1, etc., to substitute $\frac{r_0 s_0}{I_0}, \frac{r_1 s_1}{I_1}$, etc., in the summations, instead of $r_0 s_0$, $r_1 s_1$, etc.; I_0 I_1, etc., being the values of I for the cross section of the beam at the different points. Bx, Dy, etc., having been arranged so that the areas balance with these substitutions for $r_0 s_0$, $r_1 s_1$, the bending moments will be equal to the horizontal thrust multiplied by the ordinates $r_0 s_0$, $r_1 s_1$, etc.

If the section of the beam varies in such a manner that I is everywhere proportioned to the strain, the values of $\frac{r_0 s_0}{I_0}, \frac{r_1 s_1}{I_1}$, etc., are constant, and the derived curve is a series of straight lines; the areas to be balanced are triangular, and if the proportion, or the constant $\frac{r s}{I}$ is the same for each piece of the beam lying between the points of contrary flexure, all the straight lines will cut the axis A_0 F_0 at the same angle, and the approximation may be made with much greater facility than if the section of the beam were uniform.

On Fig. H, the straight lines A T, T U, U F', have been drawn so that the angles T e B_0, T g B_0, and U k D_0 are equal to one another; and the areas A A_0 e, f B_0 g, and h D_0 k are respectively equal to the areas e T f B_0, g U h D_0, and k F' F_0. The points of contrary flexure a' and β', where the bending moment is zero, are determined by drawing the lines T α', U β_1 through T and U parallel to A A_0: these lines will cut the curve of equilibrium in the points ρ' and σ'. Joining the points A and ρ', the line A ρ' produced will cut the line B x in the point x_1, and the points x_1 and σ' being joined, the line x_1 σ produced will cut the line D y in the point z. B x_1 and D z are the bending moments at B and D on the above supposition. It appears that in the case represented by Fig. H, which is probably an extreme one, the condition that the section varies as the strain, instead of being constant, involves an alteration of the points x and y to x_1 and z. On the whole, the bending moments of the large spans are not materially altered, and the Author observes that Mr. Heppel has made a similar remark. In the first case the stress per square inch on the outer surfaces of the beam would be of the same amount throughout; in the second it would vary as the bending moment.

Should it be desired to obtain the pressures on the piers, this may be done by taking moments for each pier successively, beginning with the end span, and including the moments H$\times$B x, H$\times$D y, etc., as follows:

Let W_1 be the load on the first span, and p the horizontal distance from B of the vertical line passing through the centre of gravity of W_1. In like manner for the second span, let W_2 be the load, and q the horizontal distance from D of the vertical line which passes through the centre of gravity of W_2: and let W_3, W_4, etc., r, s, etc., be corresponding quantities for the succeeding spans. Then calling s_1, s_2, s_3, etc., the lengths of the spans reckoning from A towards the right, and r_0, r_1, r_2, r_3, etc., the upward pressures at the piers beginning from A, r_0 being the upward pressure at A, if moments be taken round the ends of the 1st, 2d, 3d, etc., spans successively, the following equations are obtained:

$$W_1 p + H.Bx - r_0 s_1 = 0$$

$$W_2 q + W_1 (p + s_2) + H.Dy - r_1 s_2 - r_0 (s_1 + s_2) = 0.$$

etc. . . etc. . . etc.

From the first of these equations r_0 may be found, and by inserting this value of r_0 in the second equation, r_1 may be found, and so on for r_2, r_3, etc.

In these equations B x, D y, etc., are to be

reckoned as positive if x, y, etc. are below the line A B; the moment of the horizontal thrust then tends to turn the system in the same direction as the weights W_1, W_2, etc. In Fig. H, B x is negative, and D y positive.

If only one span be considered, the method above described affords a simple means of proving all the propositions relating to stress and deflection, for a beam with the ends free, or with one or both ends "fixed;" and with the load either acting at a given point or uniformly distributed over the span.

The action of oblique forces will now be considered.

(To be continued.)

BUILDING-STONES.

From "The Architect."

It is now nearly thirty years since Mr. George Wilkinson, at that time superintending architect to the Irish Poor Law Commission, instituted a series of experiments on the building-stones of Ireland. His object was to discover their resistance to a crushing force, their transverse strength when loaded in the middle and supported at the ends; and, lastly, their absorbing power, so as to infer their action under atmospheric influence, probably the most important point in such an investigation. About six hundred specimens were operated on, including all the varieties of stone in the country, from the basalt of the Giant's Causeway and the granite of Dalkey to the soft clay-slate of Bantry, the melancholy-looking calp of the midland district, and the white marble of Connemara. The results of the experiments were communicated to the Geological Society of Dublin, and were afterwards republished in Mr. Wilkinson's "Ancient Architecture and Practical Geology of Ireland."

We refer to these experiments for two reasons. In the first place, if they had comprised the building-stones of England and Scotland as well as of other countries, Mr. Hull thinks so much of them that he says it would not be necessary for him to compile the present work. In the second place, we consider it is remarkable that long as the time has been since these experiments were made they may be said to stand alone as examples of a systematic application of scientific investigation to stone. It is no exaggeration to say that science has troubled itself about stone less than any other material we employ in building. A man may study the best geological works without in the end being any wiser as to what are the characteristics of good building stones, or whether there is any relation between particular fossils and the endurance of the material in which they are found. The following extract on the choice of stone from Mr. Hull's book does not, perhaps, amount to much, nor could we always adopt the stone he recommends, but can the reader call to mind any geological treatise in which more precise advice is given?

"Such climates as those of the British Islands, the north-west of Europe, and those portions of North America are the most trying and destructive to buildings of which the materials are of a porous structure, or contain large proportions of calcareous matter; and here chemical composition, structure, and density, all become elements for the consideration in the choice of a stone for buildings intended to be lasting. The presence in such countries of smoke, of sulphurous, hydrochloric, and other acids, powerfully aids in the destructive effect of rain or moisture; for the rain itself takes up a considerable amount of the acid from the air, and spreads it over the exposed surfaces of the buildings. The reader will scarcely need to be reminded that limestones and dolomites are especially subject to disintegration from the influence of rain charged with acid; and this country presents numerous unhappy examples of its effects. Of these, perhaps, the cases of St. Mary Redcliffe's Church in Bristol, the New Houses of Parliament, and Henry VII.'s Chapel in Westminster Abbey are the most instructive examples: the first built of oolitic limestone, the second of dolomite, and the third of Caen stone—a white limestone of Normandy of Jurassic age. Even portions of this exquisitely beautiful structure, restored with Bath oolite about a quarter of a century ago, have given way before the influence of an atmosphere charged with smoke and dripping with moisture throughout a large portion of the year.

"For such climates, therefore, limestones,

especially soft granular and porous kinds, should, as far as possible, be avoided, and even sandstones which contain a notable percentage of calcareous matter in the form of a cement. The best kind of building stones for smoky and wet climates are silicious sandstones formed of grains of quartz cemented together by a silicious or felspathic paste. In Great Britain such rocks are largely distributed amongst the lower carboniferous formation of Scotland, the North of England, and Wales; the materials of which they are composed being derived from the disintegrated gneissose and granitic rocks which formed the land of the period. Such rocks are almost indestructible, and have been used with good results in some of the large manufacturing and smoky towns and cities of those districts where they occur. Being destitute of carbonite of lime or magnesia, or containing them only in very minute quantities, they are not exposed to the corroding action of the acids which pervade the air."

As geologists have hitherto not paid much regard to our requirements, Mr. Hull's work deserves, and is likely to be welcomed in every architect's library. It is not a treatise on the formations, with no more than incidental allusions to rocks as materials of buildings. There is nothing about palæontology in it, and there is no more mineralogy introduced than is absolutely necessary. A practical man who may be acquainted with the working and use of stone, but ignorant of geology as a science, need have no fear of not being able to follow the author, but will find instruction and entertainment in every page.

The localities in England where granite occurs are Shap Fell, in Cumberland, Anglesea, Devon, and Cornwall, Lundy Island and the Isle of Man. The Dartmoor granite has a prevailing greyish color. Stone of an excellent quality is obtained from Cheesewring, and has been employed in the construction of the London Docks, Westminster Bridge, the Thames Embankment, Rochester Bridge, and the Wellington Tomb in St. Paul's. The Cornwall granites vary in quality, structure and composition. Sometimes they are decomposed enough to produce kaolin, but that they are sometimes durable there is evidence in Waterloo Bridge, in Portland Breakwater, the Birkenhead Docks, and the Commercial Docks. Granite is exported largely from Jersey, Guernsey, and Herm. The Mount Sorel granite, although extremely hard and expensive, is esteemed for its warm rose tint. The Lundy Island granite is a quaternary compound of quartz, white felspar, and black and white mica, and is traversed by elvan dykes. The Shap granite has a rich reddish-brown base with flesh-colored crystals, abundantly distributed.

Scotland possesses some very fine granites. First is the well-known red Peterhead, largely employed for columns, tessellated pavements, and other indoor and outdoor ornamental work, for which closeness of texture and large size adapt it. The Aberdeen granite is also much used; it can also be obtained in large blocks, and takes a fine polish. The origin of granite has been an old subject of contention between "Neptunists" and "Vulcanists." Dr. Haughton, of Dublin, considers that all granites may be arranged into two great classes, namely, metamorphic and eruptive, each having specialties of composition and structure. The Aberdeen, he considers, belongs to the former, and the Peterhead to the latter class, being also the more modern. A greyish granite is largely quarried in Craignair and Creetown in Kirkcudbrightshire; in the Island of Arran there are two varieties, a coarse-grained and a fine-grained of similar composition, and the Isle of Mull produces both pink and red granites, which are now quarried by the Scottish Granite Company.

In Ireland there are four great granite districts, viz., Donegal on the north-west, Galway and Mayo on the west, Wicklow and Wexford on the south-east, and Down and Armagh on the north-east. The Donegal granite is sometimes made up of four minerals and sometimes of five, presents a bedded aspect, and branches off occasionally as dykes into the adjoining metamorphic rocks. There can be no doubt that a fine ornamental stone could be obtained from these quarries. The Galway granites have at least two varieties; one, which is of great beauty, is porphyritic, having large crystals of red orthoclase imbedded in quartz, orthoclase, greenish oligoclase, and mica, a combination characteristic of Galway granite. The Leinster district extends from near Dublin to New Ross. The prevailing color is light grey, and the stone has been much used in the Dublin buildings, but there is great variation in the durability when taken from different parts of the district.

FESTINIOG AS A TYPE.

From "Engineering."

The Festiniog Railway has been worked almost threadbare. There has been so much written about it; so many people have visited it; advocates of narrow gauge have pointed at it as the triumphant solution of a vexed question; opponents to the narrow gauge have done the same thing. It is alike an example of Mr. Bidder's "toy lines," and a proof that the whole railway practice of half a century has been entirely at fault. Those who have not seen it write most fluently (and imaginatively) about it, be they orthodox or heterodox engineers. It pays a dividend of 40 per cent., say the latter; narrow-gauge theories *must* therefore be right. It is nothing but a horse track turned into a tramway to carry slates from quarries down hill to a port, cry the former; therefore it proves nothing. Twenty miles an hour upon it approximates to wilful murder, argue many; not at all, says Mr. Spooner, and drives his engines (Fairlie's) at double that speed.

The fact is that both sides, striving to make out a good case, overshoot the mark, exaggerate for or against, and argue, not upon the Festiniog Railway as it actually is, but only as they are pleased to consider it exists. It may be worth while, then, to endeavor to arrive at some definite conclusions, which may serve as a guide, and show how far this line of world-wide fame may be taken as a type, and in what respects it differs, whether for better or worse, from ordinary narrow-gauge lines, and what lessons it teaches which may be applied in general practice. To ascertain this, we have to consider the circumstances under which it was made; the cost of its construction; that of its maintenance and working; the nature of its traffic, and the conditions which regulate that traffic. We may first answer these questions very briefly. The circumstances under which it was made were very unfavorable; the cost of its construction has been actually high, but comparatively cheap; the nature of the traffic and the conditions which regulate that traffic are greatly in its favor.

When the line was undertaken in 1832 it was never contemplated to use steam power upon it. The fine slates from the Dinas quarries had to be brought down to Portmadoc for shipment, at a level 1,000 ft. below the workings, but there was nothing to go up save empty wagons, odd stores, coals, and quarrymen; when the road was made, gravity worked the whole of the heavy traffic down, and horses the light traffic up, and as the wagons were built to suit the requirements of the line, and as it was to be a horse-worked tramway, not a steam-worked railway, curves under 2 chains radius, and gradients less than 1 in 80, were adopted with the 1 ft. 11½ in. gauge that was chosen. It was truly fortunate that the line was laid thus, though Mr. Spooner little thought when he made it in 1832 that it was destined to become one of the famous railways of the world 40 years after, and help forward so greatly the cause of narrow gauge. Being then only a tramroad and not a railway, it was built to fulfil as nearly as possible the requirements of the traffic: it ran along the high road, it crossed ravines upon the tops of walls, it skirted hills, midway of their heights, on narrow side cuts, clinging close to the mountain side, and winding in and out at the bidding of the natural contour, now and then through cuttings, and twice through miniature tunnels,—one of them half a mile long, however. And in this way the Festiniog tramway was made for about £2,500 a mile with rails weighing 16 lbs. to the yard. In 1863, the traffic having greatly increased, Mr. C. E. Spooner determined upon substituting steam for horse-power, and adding passenger carriages to the long trains of slate wagons. How this experiment answered is a matter of history, as well as the later and equally important epoch in the history of the line, when Mr. Spooner, finding that a single pair of rails was insufficient for the growing traffic, applied for powers to double the track, but was saved the labor, the expense, and the delay of so doing by adopting the Fairlie system in 1869. The cost of alteration, including heavier rails (they weigh now 48⅔ lbs. to the yard), rolling stock, sheds, shops, etc., have raised the total cost of constructing the 14½ miles of line to upwards of £56,000, or about £6,000 a mile, apparently a considerable sum when the limited width of formation, the minuteness of the gauge, the steep gradients and sharp curves, the small quantity of rolling stock, and the miniature

repairing shops and sheds are taken into consideration; but it must be remembered that the line runs for the whole of its length through extremely difficult country, that in this sum is included the high road in the long Traethmawr embankment (built many years ago to reclaim land from the sea), and that the most essential parts of the line—the road bed and permanent way—are perfect. The question to be asked, therefore, is, not how much the line actually cost, but what would have been the outlay had it been built upon a 4 ft. 8½ in. gauge.

We have said that the direction and the nature of the traffic upon the Festiniog Railway are all in its favor. This is an important fact not sufficiently considered, especially in America, by ardent advocates of narrow gauge. A line, the freight traffic of which is of only one class, which is regular in its amount, and pays high charges, and which is all down hill, works evidently under great advantages as compared with a railway that has to do a mixed uncertain business in each direction, at low freight rates. This is unquestionable, and it is for these very reasons that the Festiniog Railway has earned for itself the £50,000 required to improve it to its present condition, and is able to pay 29½ per cent. upon its original capital. But if the line had been enlarged to the orthodox gauge; if £150,000 instead of one-third the amount had been invested, as must have been the case, in making the change; if rolling stock and shops had been furnished to correspond, we can hardly imagine that the most bigoted advocates for broad gauge—those Australian engineers, for example, whose evil counsels have prevailed in Victoria—would argue that the Festiniog Railway would pay 29½ percent. dividend. But we are told this is not a railway—it is only a tramway, steam worked, it is true, and having all advantages in its favor. We freely admit that it is not a railway—in the Great George street sense of the word—and the proprietors may congratulate themselves upon the fact. It will be worth while to compare a year's work on the Festiniog with the annual traffic on some of the Victorian lines which are 5 ft. 3 in. gauge, and which ruinous gauge is to be maintained. Putting out of consideration the 254 miles of 5 ft. 3 in. gauge already built in that colony at an outlay of nine millions and a quarter sterling, we may look at the new lines which are to be commenced, and the probable traffic to be derived from them. The length of each of four lines proposed by Mr. Higginbotham is about 150 miles, and the estimated traffic amounts to 40,000 tons a year for the four lines collectively. In 1869 there were carried on the Festiniog Railway 136,732 tons of goods and minerals, or more than three times the traffic for which 600 miles of railway, 5 ft. 3 in. gauge, are to be built, if the money for so doing can be raised. In addition, 97,000 passengers were carried through the year; the traffic receipts from this source alone reaching £700 per month during the summer. Yet the Festiniog Railway is not worked up to one-half of its full capacity; there are but five trains a day, there is no night traffic, and no Sunday business at all. The traffic returns upon the line are therefore enormous compared with those to be obtained in Victoria for the broad gauge extensions, and the number of trains daily show that 50, and not 30, per cent. could be returned upon the capital, if there was work enough to be done. In short, the little Festiniog Railway carries as many passengers every year as any one of the Victorian extensions will obtain; it carries a large amount of mixed goods, and 120,000 tons of minerals besides. It must be borne in mind, also, that the general freight is all carried up the heavy gradients of the line, and that hauling back the empty slate trucks forms a considerable item in the expenditure.

We have seen now that the Festiniog Railway proves conclusively that even such a narrow gauge is thoroughly adapted for general traffic, far heavier than can be obtained in Australia or in India through the districts where extensions are contemplated, and that if that line exists and is worked under favorable circumstances, the result is shown in the exceptionally high dividends paid. There is, however, one point to which we are bound to call attention, which gives to the line a greater advantage than others can hope to enjoy. It has Mr. Spooner, C.E., for an engineer, and this gentleman shows something more than professional skill in his work; he shows an earnestness and enthusiasm, we may almost say an absolute devotion for the Festiniog Railway; the line from end to end is constantly under his eye; and every detail of construction, management, or repair, receives his personal consideration. We suppose it would be difficult, if not impossible, to find elsewhere 14 miles of permanent way similar to that

laid down between Portmadoc and Dinas. We noticed within the last few days, that the constant heavy rains which have deluged that district in common with all the rest of England, have had no effect upon the ballast; there being no signs of subsidence or any shifting of the sleepers, whilst the rigid fish plates employed throughout the line maintain all the joints in a perfect condition. And, as with the permanent way, so it is with every other detail of the line; everything is adapted to fulfil its purpose to the best effect, not with a blind deference to what has been done before.

But though it is impossible that narrow gauge engineers can follow—except in a few favored instances—Mr. Spooner's example, yet they may benefit greatly by his experience, especially with regard to the permanent way; the narrower the gauge, the greater is the necessity for approaching to perfection in the road-bed; the greater is the danger of any irregularity of the rails, because such irregularities impart oscillation to vehicles passing over them, perhaps scarcely perceptible if the rails are far apart, but gradually increasing until they become absolutely dangerous as the width of the gauge diminishes.

The Festiniog Railway proves clearly the possibility of carrying on an extensive passenger traffic upon a narrow gauge, although the actual numbers conveyed upon it are comparatively insignificant; but passenger traffic has been an incidental, not a principal feature of the line, and the actual carriage stock, though it has been found suitable for the purpose, was open to improvement. This stock was between 9 ft. and 10 ft. long, 6 ft. 3 in. wide outside, and of ample height, with the seats running longitudinally. The increasing passenger traffic has, however, led Mr. Spooner to construct an entirely new type of passenger rolling stock, which has been found to answer admirably. The new carriages are 37 ft. long over all, of the same width as the other stock, and they are divided transversely into ordinary compartments, with the exception of the two ends. Each seat gives ample accommodation for three persons. The carriage rests upon two four-wheeled bogies, the frames of which are bent downwards under the bottom of the carriage, so as not to interfere with the sitting space in the end compartments, the seats in which are, however, placed longitudinally, instead of transversely, in order that the wheels of the bogies may have sufficient space. The floor of the stock is, of course, very near the ground, as is the case with all the passenger carriages upon the Festiniog line. We shall shortly publish detailed drawings of this new stock; meanwhile we may observe that it is the most remarkable that has yet been built for regular traffic. Its length is more than 18 times the width of the gauge, whilst the width is more than 3 times. The length of rolling stock for the Denver and Rio Grande Railroad is less than 12 times, whilst the width is 2.33 times that of the gauge. A long working experience has shown that the width of vehicle adopted on the Festiniog Railway is not excessive. We have travelled over the line in one of the short carriages, with longitudinal seats, with one side of the carriage loaded with at least 800 lbs. weight of passengers, the other side being unloaded, without observing the slightest tendency to oscillation, even in passing round curves of $1\frac{3}{4}$ chains radius, at comparatively high speeds; but such a result could not have been obtained if the permanent way were not in a perfect condition.

The Festiniog Railway has shown clearly that moderate speeds may be adopted in regular working, and that high speeds can be reached with perfect safety. A favorite argument of the opponents of narrow gauge has been this, that the velocities must be kept so low, if danger is to be avoided, that traffic requirements, even assuming capacity to be sufficient, cannot be fulfilled. Ten or fifteen miles an hour, or even twenty as an exceptional maximum, has been assigned as the limits of speed that must be set upon lines, not of 1 ft. $11\frac{1}{2}$ in. gauge, but on those of 3 ft. 6 in. Facts at Festiniog refute all these arguments; 30 and 35 miles an hour, upon those steep gradients and sharp curves, is not an uncommon working speed, and on a recent occasion we stood upon the foot-plate of the "James Spooner"—when she made over 42 miles an hour—without experiencing the slightest indication or sense of danger. Of course, it is impossible to say absolutely how closely the limit of safety was approached, but all indications of danger were wanting, and the engine travelled as smoothly and as steadily as it it was running on a 4 ft. $8\frac{1}{2}$ in. gauge, instead of one of 2 ft. The experience gained by several years of daily work conclusively shows how fallacious are these

arguments, advanced to prove that speed and narrow gauge cannot go together. But here we must repeat that at Festiniog there exist the two elements of safety at high speeds; the first of these is the permanent way, the second, the Fairlie engine. The perfect condition of the former, and the care with which the parabolic curves have been laid out, permit the long trains which are worked upon the line to sweep around the hill sides at comparative high speeds with the utmost steadiness, whilst the engines are essentially correct in principle for the work they have to do. Attempt to ride at 35 miles an hour upon either of the miniature ordinary engines, which were exclusively employed before the days of the "Little Wonder," and you begin to tremble for the consequences; slowly they run with tolerable smoothness, but as the speed augments, the uneasiness of the engine and of the experimenter increases also, until, at 35 miles, the roll and gallop become subjects for legitimate alarm.

But the Fairlie engine has done much more than to enable the speed of working on this line to be increased. With the ordinary engines first employed, the insignificant loads carried, combined with the low speeds (the Board of Trade had limited them to 12 miles an hour), rendered the single pair of rails insufficient for the traffic, and, as we said, it was intended to apply for powers to double the line in order to increase its capacity. This intention, however, was abandoned, and the "Little Wonder" was placed upon the line in order to ascertain how far the double-bogie engine would increase the working power of the single pair of rails. The consequence was that instead of being restricted to take slowly up a gross load (without the engine, which weighed 10 tons) of 45 tons, no less than 108 tons could be hauled, whilst on the return journey the respective weights of the train for the 10-ton single engine, and the 19½-ton Fairlie, were 93 tons and 336½ tons, or more than three times the paying load, the speed also, as we have seen, being increased. Under these circumstances there was no further necessity to double the line, the Fairlie engine having in effect done so. The "James Spooner," the second locomotive of this class, just placed upon the road, will still further simplify the work, and the number of daily trains to and from Portmadoc will be reduced from five to four.

The Festiniog Railway affords valuable data upon the subject of transshipment. At Minffordd Junction, near Portmadoc, there has recently been built an exchange station, in connection with the Cambrian railways. To this station are brought down a large number of slates, which are shifted from the narrow gauge wagons into those of the broader gauge. To the same point also come the coal wagons, which are discharged into the Festiniog trucks to be taken up into the quarries. Besides this, there are exchange sidings where, under cover, such few miscellaneous goods as arrive at Minffordd are shifted. But these, it is almost needless to say, amount to little in the course of the year. A considerable business in transshipment is, however, transacted, and although only two classes of freight have to be shifted—slates and coals—it happens that the former is one of the most difficult and costly articles to transship, whilst the latter is amongst the cheapest and simplest. The narrow and broad gauge wagons are brought alongside each other, and the carefully-packed slates (which are of most excellent quality) are taken out of the one wagon and laid in the other by hand, it being impossible to shift them in bulk on account of their fragile nature. In changing the coal from one truck to another, the 4 ft. 8½ in. wagons are brought over an elevated siding, upon a tipping table, and the side or end of the wagon being opened, the table is set at an angle, and the coal is discharged into a shoot, at the bottom of which are placed the small wagons to receive it.

The cost of unpacking and repacking the slates is sixpence per ton, that of transshipping the coal is less than a penny per ton. In the face of facts like these, which are amply borne out by the practice in America (where 6 cents a ton is a fair average), in Sweden, and elsewhere, what becomes of the false statements, and false arguments founded upon this subject, which have been so freely circulated, and which unfortunately have carried weight with them?

Two other points of great importance present themselves: the cost of working, repairs, and maintenance upon the Festiniog Railway, and its capacity for carrying mixed and bulky traffic, as applied to general narrow-gauge practice; the latter is of special importance, because it touches one of the principal arguments by which the broad-gauge clique, through Colonel Ken-

nedy, seeks to obtain a reversal of the Indian Government decision upon narrow-gauge railways. But to these points we must address ourselves on another occasion; the present article has already exceeded reasonable limits.

We are now in a position to see how far the Festiniog Railway may be regarded as a type. Proving conclusively as it does the possibility, or rather the ease of carrying upon it a considerable passenger and mixed traffic, besides a large mineral business, it is nevertheless clear that the gauge is not a suitable one for ordinary practice. The requirements it has to serve, apart from that of carrying slates, are not of that positive and urgent class inseparable from an ordinary line of railway. The passengers it conveys, are either quarrymen or dwellers in the little hill villages to which Portmadoc is as a metropolis, and tourists whose business is leisure. The goods traffic is so light as to be easily handled, and of small importance enough to wait, if necessary, upon convenience. Moreover, the line has been isolated hitherto, and though its extensions, to be carried out on a large scale, will be necessarily of the same gauge, it will be found that a certain amount of inconvenience will attend these reduced dimensions as the mileage increases and the traffic becomes more general. Besides, as we have said before, the success of the Festiniog Railway is due in a great measure to the manner in which it is maintained. Could the permanent way of all the narrow-gauge lines of the future be as that at Festiniog, a wider gauge would afford increased convenience, but would not be necessary for absolute safety. We may, however, state with confidence, that such a road-bed will not be found upon ordinary lines; and for this reason, if for none other, an increased width of gauge is required.

But we may judge from the work done by the Festiniog Railway how eminently suited for a general and extensive traffic, are lines far narrower than 4 ft. 8½ in., such, for example, as the 3 ft. 6 in. railways of Norway. Upon such a gauge is combined safety at moderately high speeds, with ample capacity in the rolling stock for every class of merchandise, and full accommodation for passengers, whilst at the same time the small light carriages and wagons can be filled with a very large proportion of paying weight. The small open Festiniog trucks, and the covered wagons, looking like dog kennels, carry 3 tons of freight for one of vehicle, but on the 3 ft. 6 in. gauge the same proportions can be maintained, and the stock is of universal utility. The answers to the two following questions are, we think, then clearly given. If so much is done at Festiniog, how much more may we not expect from lines 3 ft., a metre, or 3 ft. 6 in. gauge? And, if double the business is transacted upon the Festiniog Railway, when only worked up to half its capacity, that is to be expected from projected lines in Australia and elsewhere, would it be true economy to construct those lines 5 ft. 3 in. wide?

We have seen that the Festiniog Railway could not be worked up to its full capacity except by the use of the Fairlie engine, and it is clearly evident that without this, or some analogous system, narrow-gauge railways cannot possibly be developed. Doubtless there are many districts in which the traffic is so scanty that a minimum of steam power is ample, but upon all lines where a serious business exists, especially where there are steep gradients and sharp curves —and these are special characteristics of narrow-gauge construction—then the Fairlie engine, or a better if it can be found, must be employed. The experience gained by Mr. Spooner is not exceptional, and his testimony is to the effect, as we have seen, that with the Fairlie engine high speeds can be safely reached, two and a half or three times the load can be carried, with less than twice the weight of the ordinary engine, and with an economy of fuel equal to 25 per cent. in proportion to the work done.

As a profitable line, the Festiniog must not be taken as a narrow-gauge type. It pays large dividends upon a small capital simply because it commands high tariffs.

As an excellent example of "break of gauge, and the train of intolerable evils consequent thereupon," it may be taken as a type, proving as it does, that the cost of transshipment is not nearly so great as has been claimed, and is absolutely insignificant compared to that of building broad-gauge lines of any considerable length, to say nothing of the subsequent expense of running heavy stock only partially loaded over these lines when they are made.

Speaking generally, the Festiniog line may be regarded as an admirable example of imperfect means adapted to a successful end; somewhat cramped, it is true, by the accidental circumstances that attended its

origin, but possessing devices of a high order of merit to overcome difficulties that would have been unknown if a wider gauge had at first been adopted.

In many important points which we have noticed, we may therefore regard it as a type for the extensive system of railways for light traffic that will be built ere long in all parts of the world, and we must so continue to regard it, until we are convinced, by broad-gauge advocates, that in extravagance in construction, and costliness in working, lie the secrets of true railway economy.

THE IRON AND STEEL INDUSTRIES IN FOREIGN COUNTRIES.

By DAVID FORBES, F.R.S.

Extract from last report of Iron and Steel Institute.

ANNUAL MAKE OF CAST IRON IN THE WORLD.

In order to form something like an approximate estimate of the total annual production of cast iron on our globe, the most reliable statistics of the trade have been compiled by an American metallurgist for the year 1871, and the result shows a total of somewhat over thirteen and a quarter million of tons; the details of this figure being geographically as follows, the different countries being arranged in accordance with their actual production:

Great Britain	6,500,000
United States	1,912,000
France	1,350,000
Germany	1,250,000
Belgium	896,000
Austria	450,000
Russia	330,000
Sweden and Norway	280,000
Italy	75,000
Spain	72,000
All other countries	200,000
	13,315,000

from which it will be seen that the annual make of Great Britain is still nearly equal to the united production of the whole of the rest of the world put together.

Africa.—Much attention is now being paid to Algeria and other parts of the north of this Continent as a source of iron ore, and the exportation of iron ore has of late greatly increased, especially to France. A memoir on the Soumah Iron Mines in Algeria, by M. C. Méne, will be found in the "Revue Hebdomadaire de Chimie Scientifique et Industrielle," for May 9, 1872. These mines are readily accessible, having railway communication to a shipping port; the ores contain from 47 up to 65 per cent. metallic iron, along with some manganese, and with but very litte silica.

From information derived from Sir John Swinburne, it appears that the negro tribes in the interior of Africa, some 800 miles from Natal, are extremely expert in the manufacture of wrought iron, which they smelt in little clay furnaces, from the native ores. They sell the iron thus made, which is said to be extremely good in quality, at so low a price that it is cheaper than that which is imported by the settlers at the gold mines, who consequently employ it for their implements.

Austria.—All the accounts received from this country describe the iron and steel industries of the Austro-Hungarian Empire as advancing and in a state of great activity.

The Bessemer process for steel-making is rapidly gaining ground, and the new works at Zeltray, which are the largest in Austria, have now been in successful operation since April this year. In consequence of the demand for spiegeleisen, created by the rapidly extending use of the Bessemer system, much attention has of late been directed to the manufacture of this kind of iron in Austria. The Director of the Imperial Geological Institute, which, unlike our geological survey, occupies itself also with the practical questions connected with the development of the mineral resources of the empire, Herr Carl von Hauer, read at the May meeting, a report on this subject, in which it is announced that after a number of less successful experiments, the Jauerburg Iron Company, whose furnaces are situated at Jauerburg in Carniola, have succeeded in producing, on the large scale, spiegeleisen, containing more than 5 per cent. of carbon, along with from 12 up to 22 per cent. metallic manganese. When broken across, the spiegeleisen does not show so large bladed a fracture as the Siegen metal, and is somewhat more radiating in its crystallization; it has, however, been already employed in the Bessemer steel works in Styria and Carinthia, with

it is stated, the most satisfactory results. The iron ores from which it is produced are from the mines of Belschitza and Lepene, where they occur as lenticular deposits in the triassic limestone strata, being granular carbonates of iron, which, from their being poor in manganese, require to be smelted with an admixture of richer manganese ores from other mines.

Belgium.—The state of the iron trade in this country during the last quarter may be likened to that of England. All the ironworks have been overwhelmed with orders, and have been kept in quite unwonted activity; yet the extremely high prices, not only of the product but of the raw materials, as ironstone and coke, combined with the uncertainty as to how long this abnormal state of things may continue, have combined to bring about a feverish state of excitement which is far from healthy, and which as yet has rather kept increasing than showing any tendency to diminish.

In the Charleroi district, during the year 1871, there were 13 establishments making pig iron, which employed 2,312 workmen, and kept 27 blast furnaces in work, along with 14 standing idle. The total manufactured product of the district reached 528,120 tons; the quantity of foundry pig iron being 31,520 tons, along with 327,600 tons forge pig. In the same district were in operation 21 mechanical workshops, 42 foundries with 80 melting cupolas, and 20 rolling mills, in which were 394 puddling and 162 reheating furnaces. The total number of hands employed in the iron manufacture amounted to 10,672, producing 380,157 tons cast, and 240,702 tons wrought iron, representing a total value of about £2,900,000.

The official statistics show that the imports of iron of all kinds for the first quarter of 1872 were 47,360 tons, against 21,600 tons in the corresponding period of 1871; whilst the exports for the first quarter of 1871, amounting to 56,960 tons, during the first three months of 1872 reached 91,429 tons.

From the "Moniteur des Interêts Materiels" for the 24th August, we translate the following remarks on the situation of the Belgian iron trade at present:—"Prices have not altered except for foundry pig, which has reached 160 francs (£6 7s. 6). Everyone is awaiting news from the English market, which during the last ten days has exhibited such curious fluctuations. A reaction is feared, and the slight lowering of prices has made many fearful. Little by little foreign countries are making themselves more independent of us. Austria, who with the excellent iron of her own, only purchased ours because of its lower price, now finds it more profitable to utlize her Carinthian iron; Russia supplies herself from her ironworks in Siberia; and France, for the numerous works in progress, does not apply to us, so that the demand will lower itself to the production."

Canada.—An English Company, under the name of the "Quebec Iron Company, Limited," was registered on the 9th August, for the purpose of acquiring a freehold property of some 12,850 acres in Drummond County, Canada, abundantly timbered, and which is estimated to contain 500 tons crude or some 334 tons washed iron ore per acre, which occurs as a bed averaging about 2 ft. in thickness, and only from 1 to 3 ft. below the surface. The ore is what is called "bog" ore, a hydrated brown hematite, containing about 54 per cent. iron; and it is proposed to erect furnaces capable of producing 15,000 tons per annum, the works for so doing being only estimated to cost £10,000, which seems an extraordinarily small amount. The entire cost of manufacture, including the digging up, washing, carriage, preparation of the charcoal, and smelting of the ore is estimated at £3 per ton. The iron produced is described as "equal, if not superior to the best Swedish," a statement rather surprising, as ores of this class usually are found to contain considerably more phosphorus than the run of the Swedish native oxides which are smelted, and which rarely contain as much as one-tenth of a per cent. of this deleterious element.

At the recent half-yearly meeting of the Grand Trunk Railway Co. of Canada, the report of the engineer stated that in the 110 miles of Bessemer steel rails which had been laid down on their line, only some eight or ten had broken, whereas of the iron rails, they were accustomed every winter to have from 3,500 to 4,000 rails fractured, a result which seems to tell greatly in favor of the employment of steel rails instead of iron in countries like Canada, where they are exposed to very low temperatures.

France.—The French ironworks are rapidly recovering their position, and are everywhere actively occupied with an abundance of orders on hand.

The charcoal iron trade has also been much more active in the Haute-Marne district, and in Comte several furnaces have recently been put in blast which had been long standing idle; in this district it is reported that some 45 furnaces will soon be in operation. A new company entitled la Societe des forges de la Seine, has been formed for carrying on the ironworks situated on the banks of that river near Charenton.

The Compagnie de Terrenoire in the Loire district are completing a third blast furnace intended to produce Bessemer pig for the supply of their steel works.

In 1871, the production of steel in the shape of rails, tyres, bars, etc., made by the Bessemer or Siemens-Martin process, is given at 253,662 tons, along with 841,000 tons merchant bars, rails, plates, etc., and 311,000 tons pig iron.

From the above statement it will be seen that the state of the iron trade in France is still much behind what it was before the commencement of the late war. In criticising these figures, it must, however, be remembered that a large portion of the iron-producing districts of France was, at the termination of the war, transferred to Germany by the annexation of Alsace and Lorraine.

We extract the following analyses of French iron ores made in the Chemical Laboratory of the Département de Mézèires, from the report published in the "Annales des Mines," 1872, I., pp. 91–96:—

	a.	*b.*	*c.*	*d.*	*e.*	*f.*	*g.*
Sesquioxide of iron	44.75	31.46	64 20	72.08	72.60	0 29	72 42
Protoxide of iron.....	0.82	.....	.....	... .	... .	47.57	....
Silica	47.98	60.00	11 42	7.00	0 25	7 10	7 87
Alumina	0.11	0.20	0.41	2.76	.....	1.32	1 60
Lime	trace.	trace.	5 00	0.20	7.00	7.11	0 40
Magnesia.....	.....	.....	1.08	.....	0.39	.....	0 05
Sulphuric acid	0.34	0.34	0.14	0 17	0.09	0.95	trace.
Phosphoric acid....	.....	.....	.....	0.07	0.22	0 10	trace.
Water by hygrometric..	1.10	2.00	3.75	1.80	2.87	0.53	trace.
Water loss on calcination	4.50	6.00	14.00	15.80	16.58	35.08	17.10
	99.60	100.00	100.00	99 88	100.00	100.00	99.44
Metallic iron, per cent..	31.95	22.02	44.94	50.45	50.32	37.20	50.70

(*a.*) Iron ore newly discovered in the forest of Marquisades, Commune d'Anchamps, which occurs in the Devonian slates of the Ardennes; the mineral which is called in the district "mine rouge," is a hematite, and is in the vicinity of the Vireux blast furnaces.

(*b.*) Iron ores from same place as last, called "mine jaune," which is an arenaceous yellow ochre. Neither of these ores contains either phosphorus or manganese.

(*c.*) Nodular iron ore found in the compact gray marls above the astarte limestone of the Ardennes, near Bayonville, but is not abundant enough to be of importance practically.

(*d e f.*) Iron ores from the Portland limestone formation at Ancerville, smelted at the blast furnaces near Saint-Dizier; (*d*) being pisolitic limonite of a greenish yellow color, traversed by veins of compact brown oxide; (*e*) red hydrous hematite with fossil impressions; (*f*) a carbonate of iron, which oxidizes rapidly when exposed to the air.

(*g.*) Iron ore from deposits in the inferior, and great oolite formation at Cernion, in the Ardennes, now used in the coke blast furnaces at Vireux. In former years, when wood was more abundant, these ores were largely used in the charcoal blast furnaces, and appear to have been employed even in very ancient periods, ruins of rude furnaces made of white quartzite being still seen, which are surrounded by great heaps of black compact, and very heavy slags, which are carted away to be smelted in the present blast furnaces at Vireux.

An analysis of these slags showed their composition to be as follows:

Protoxide of iron.....	74.26
Silica.....	20.47
Alumina.....	1.50
Lime	2.25
Sulphuric acid.....	0.09
Phosphoric acid	0.42
	98 99
Metallic iron.....	57.35

In many other places in the Department of Ardennes enormous mounds of similar slags are found, which testify to the magnitude of the smelting operations carried on by the ancients in these regions. Some of these slags are not fit to be re-smelted or used for fettling, but others are largely utilized for this latter purpose, especially when employed in combination with limestone; the analysis of the ancient slags of Belval in the canton of Buzaney, which are employed in the puddling furnaces at the Flize Iron Works, is here appended:

Sesquioxide of iron	66.19
" manganese	traces.
Silica	10.00
Alumina	1.40
Lime	5 00
Magnesia	0.50
Phosphoric acid	2.16
Sulphuric acid	0.25
Water hygroscopic	4.50
Fragments of charcoal, etc.	10.00
	100.00

Germany.—We have not been able to meet with any statistical information showing the extent of the various departments of the iron and steel industries of Germany since it has become an empire, the latest information not extending to a later date than the year 1870, in which year the exploration of the iron mines, which were 1,275 in number, occupied 27,289 workmen, and produced a total of 3,839,222 tons (metrical) iron ores, valued at 8,037,799 Prussian dollars, or about £1,390,000. The particulars of this amount, and the quantities of iron ore extracted from the mines worked in the several countries which are regarded as forming United Germany are as follows:—

Country.	Metrical Tons.	Value in Prussian dollars.
Prussia	2,676,400	6,549 793
Anhalt	1,224	3,426
Luxemburg	911,695	920,971
Bavaria	97,030	230,843
Saxony	16,011	78,570
Wurtemburg	29,480	73,927
Baden	84	343
Hesse	47,163	106,746
Thuringia	13,047	27,898
Mecklenburg	.....	.....
Oldenburg	1.532	1,218
Brunswick	45,508	44,064

In Bavaria, according to the latest statistical information, 97,030 tons of iron ore were raised in 1870; and the iron works during the same year turned out 43,968 tons pig iron, 11,633 tons iron castings, 60,278 tons bar iron, and 1,799 tons plate and sheet iron. The want of coal prevents Bavaria from reaping the full advantages from the large quantities of hematite and oolitic ores, which have to be smelted with fuel imported from Saxony or Westphalia. The largest iron works in Bavaria are the Maximilian's Huette, near Regensburg. The Kaiserlautern Iron Works paid last year, 1871, a dividend of 14 per cent. to its shareholders.

An English company, called the "Brittania Iron Mining and Spiegeleisen Company (Limited)," has very recently been formed "for the development of mineral properties in Prussia; but as yet we have no information as to their proposed plan of operations.

India.—A deposit of iron ore is reported as occurring in the Hazareebaugh district, and to extend over some five hundred square miles of country. It is stated to contain 70 per cent. of metallic iron, along with a little manganese, and as it is not far from the Damooda coalfield, the discovery is supposed to be very important. Discoveries of iron ore, said to be of good quality, are also announced from the Kuramam district of the Nizam's territories, and specimens have been sent to Hyderabad for examination.

With reference to the wrought iron pillar at the Mosque of the Kutub at Delhi, alluded to in the first quarterly report for this year, Lieutenant Spratt, of the Royal Engineers, then stationed at Delhi, has kindly, in answer to our inquiries, procured on the spot some information, which enables some of the statements as to its dimensions to be corrected; according to these data, the height of the column above ground is only 24 ft., and 3 ft. below ground it ends in a bulb like an onion, which is held in its place by eight short thick rods of iron, on which it rests, and which at their lower extremity are let into blocks of stone, in which they are secured by lead. The iron of which it is made, which appears to have been originally in blooms of about 50 lbs. weight each, has been examined by Dr. Murray Thomson, of the College at Roorkee, who found it to be wrought iron, possessing a specific gravity of 7.66. Although these measurements greatly reduce the reported size of the column, it still remains

equally difficult to explain the mode of its manufacture in so early a period.

Japan.—In the first quarter's report for this year, a mention was made of the process of iron smelting in Japan, in which large blooms of wrought iron, weighing above 1,300 lbs., were produced direct from the ore by a sort of magnified Catalan process; from the same informant, M. Sevoz, it appears that the iron ore employed is a ferruginous black sand, washed out of the decomposed granites, which is a mixture of 90.3 per cent. magnetic oxide of iron, attracted by the magnet with 9.7 per cent. of nonmagnetic titanoferrite or ilmenite. The ore, as washed previous to smelting, affords 61.5 per cent. cast iron; the iron produced costs about £8 per ton, the charcoal being only estimated at from 6s. 6d. to 7s. per ton. The slag produced along with the bloom is very rich in iron, containing, according to M. Sevoz's analysis—

Silica	28.50
Alumina	8.37
Oxide of iron	62.25
Lime	1.74
Soda	2.13
	101.00

In M. Sevoz's report to the Japanese Government, he recommended the erection of a small blast furnace, and some Franche-Comté hearths, for making wrought iron, estimating that, including repayment of the capital in five years, the iron would not cost above £4 per ton, or one half the present cost.

We understand, however, from more recent accounts, that the attempts which have been already made to smelt these sands in a blast furnace, have proved unsuccessful.

New Caledonia.—As a curiosity, it may be mentioned that the chief of the scientific department of the French Exploring Expedition in the Eastern seas, reports that the interior of Owen Island, which is only separated from New Caledonia by the narrow but deep wooden channel, is almost entirely composed of iron ore, usually of a spheroidal form, and forming occasionally large tablelands several thousand yards square, which, when acted upon by the rain, leave gigantic conical mounds of iron ore, such as the cone of Mamié, seen on the northeast of the island. Few plants grow on this metallic soil, and as yet it does not appear that the iron ore has ever been utilized by the inhabitants.

New South Wales.—We are not aware of any works in which iron is smelted from its ores being in successful operation in any part of Australasia, although some attempts have been made in New Zealand as well as New South Wales. A recent communication from the latter country states that the Fitzroy Iron Mines, on which more than £150,000 had been expended without adequate returns, have recently been sold to an English company, which proposes to put them in immediate operation, and to erect blast furnaces for smelting the ore, which is said to be very rich in iron and in great abundance.

Norway.—At this year's exhibition, at Copenhagen, the iron manufactures of this country play a very insignificant part, none of the few remaining charcoal blast furnaces being represented, and the whole interest of this department being concentrated in the products of the cast steel works from the Naes and Egelands Iron Works belonging to Messrs. Jacob Aal & Son. Besides a very fine show of cutting tools of all descriptions, the finish of which left nothing to be desired, these works displayed a series of cast-steel cannon of various calibres, such as are used in the Norwegian mounted artillery, one of which, after having resisted the most severe tests, when subsequently burst on purpose to examine into the effects of such treatment, merely showed a split along one side of the bore for about two-thirds of its length without detaching a single fragment or splinter, thus fully proving the admirable quality of the steel for this purpose. The cast steel made at the Naes Works is all on the old English system of first converting the bar iron into blister steel, and then smelting this into cast steel in crucibles.

The titaniferous iron ore mines of Soholt and Solner, near Aalesund, on the west coast of Norway, which have for many years been in the market, have been taken over for the immense sum of £60,000 (one half in shares of the company) by a new English company. The ores are said to contain 43 per cent. metallic iron without any sulphur or phosphorus; both these elements were, however, found in appreciable quantity in samples of the ore sent to the author of this report direct from the mines. It may be mentioned, upon the best authority, that the results of several years smelting of Norwegian titanic iron ores in the Norwegian Titanic Iron Company's blast furnaces at Norton, near Stockton-on-Tees,

do not in any way warrant so low an estimate of the cost of smelting such ores in England as is particularized in the prospectus of the above company.

Russia.—An English company, entitled the "Finland Charcoal Iron Works Company, Limited," has recently been brought before the public with the object of purchasing an estate at Uleaborg, in Finland, in order to carry on iron smelting there for the production of charcoal iron.

The manufacture of cast steel at the Government works at Perma and Obouchow is progressing satisfactorily, the cannon made from the Russian cast steel being affirmed to be more sound and durable, as well as less liable to burst, than those made by Krupp. At present the Perma foundry is engaged in casting 26 9-in. and one 11-in. steel mortars, while Obouchow has in hand 32 9-in steel coast guns, all for the Russian Government.

Spain.—A new English company, called the "Somorostro Iron Ore Company, Limited," has recently been formed for acquiring and working the Mora la Union, Malæspera and Julia Iron Mines, and the lease of the Ollargan Iron Mines, situated near Bilbao, in Spain. Some of these mines, at least, produce iron ore very different in character, and are located in quite another district from that in which the well-known Somorostro Red Hydrous Hematite Mines are situated. Another English company, called the "Cantabrian Iron Company, Limited," was registered on the 15th August, the specified object being to carry on mining and smelting operations in Spain.

It is also rumored that an English limited company is about to be formed for the purchase of the old charcoal-iron works at Sargedelos, in Galicia, known as the Royal Sargedelos Foundry and Iron Works, along with certain concessions of iron ore situated at Ferrol and Pontevedra, from which it is proposed to export iron ore to England and other parts of the Continent.

Sweden.—The greatest excitement prevails in all the iron-producing districts of this country, the iron-masters everywhere exerting themselves to their utmost to increase their turn-out, in order to reap the benefits of the present extraordinary high price of iron; so that the total production of iron in Sweden this year will be even in excess of what it was in 1871, notwithstanding that the make in that year was larger than in any previous one. New charcoal blast furnaces and Bessemer works are being erected on all sides, amongst which may be mentioned two blast furnaces with Bessemer works and rolling mill at Bongbro, near Nya Kobberberg, two blast furnaces with Bessemer works at Bjorneborg, one blast furnace near Linda, now finished, Bessemer works at Stjernfors and Nyhammer, the latter having been recently put in operation,—the Bessemer process being now everywhere adopted in Sweden, the cast iron being tapped into the converter direct from the blast furnace, and, as a rule, blown without the addition of spiegeleisen. A number of samples of Bessemer steel from different works in Sweden are exhibited at the Exposition at Copenhagen, and amongst some extremely fine specimens are shown Herr. Chr. Aspelin from the Fagersta and Westanfors Works. In the same Exhibition, the Fingspong and Ankarsium Iron Works, so long known for their cast iron cannon and projectiles—a branch of the trade in which these establishments have long and justly been celebrated—show numerous samples of their iron and projectiles, as well as a perforated armor-plate to show the effect of their projectiles.

In Sweden, the production of what is called cannon iron, or cast iron specially made for casting artillery from, is now confined to two ironworks—Finspong and Ankarsrum—in both of which the iron is made from the same raw materials and in precisely the same manner; the latter of these works, however, only manufacture projectiles, whilst Finspong, in addition, is well known for its cannon foundry.

The iron ore from which the cast iron intended for founding cannons is smelted, is a mixture of native magnetic oxides of iron from three different mines called respectively the Fœrola, Nartorps, and Stenebo mines. In this mixture 80 per cent. of the Fœrola ore, which has been celebrated and employed in Sweden for this purpose during the last three centuries, is smelted along with 10 per cent. of each of the other two ores, with charcoal, using cold blast, and is tapped into pigs, which are carefully assorted, according to their hardness, into ten classes, a test-bar, 2 ft. long and 3 in. in diameter, being cast along with each tapping, and the degree of hardness estimated from the appearance of its fracture —which in Class I. is altogether dark and pretty strongly graphitic, whereas No. X is

perfectly white without a trace of graphite. The pig iron is re-melted in reverberatory furnaces, and the classes employed, both for cannons as well as projectiles, are usually Nos. 3, 4, and 5—occasionally No. 2, but never higher than No. 6.

The specific gravity of the iron (taken from the test-bars) of the classes employed for cannons and projectiles varies between 7.30 and 7.45, that of the iron in the cannons after casting from 7.22 to 7.30; but the specific gravity of some of the projectiles which are cast in chills can rise as high as 7.65. The chemical composition of the cannon iron after re-melting in the reverberatory furnace is as follows:—

Iron	95.68
Carbon, combined	1.41
" graphitic	2.05
Silicon	0.48
Manganese	0.25
Aluminium and calcium	nil.
Copper	trace.
Sulphur	0.13
Phosphorus	trace.
	100.00

Two rings of the cannon iron are exhibited, which show that the metal has an amount of elasticity in itself which is something extraordinary for cast iron.

All cannons of the size of 5 in. (about 24-pounders) and larger calibre are cast at Finspong, using a rising and rotating stream of metal and having a hollow core, kept cool by a stream, first of water and subsequently of air; small cannon are usually cast from above, and massive throughout. Along with each large cannon a smaller one of from 4 to 6 lbs. calibre is cast at the same time, whereby the quality of the larger piece can be comparatively ascertained.

The pointed conical or ogival projectiles for use against armor plates are cast with the lower or cylindrical portion in moulds of dry sand, whilst the upper or point is in iron chills. These projectiles have, upon trials made in Sweden, Denmark, and Holland, perforated armor of 8 in. massive and 14½ in. combined iron plates respectively, besides the oak backing of some 18 in. thick and an inner iron plate lining.

The total exportation of iron and steel from the port of Gothenburg during the first six months of the last three years is given from the Custom House returns as follows:—

	Swedish centners.		English tons.
1872, first half year	728,523 97	=	30,355
1871, " "	808,809.98	=	33,700
1870, " "	922,572 00	=	38,440

A comparison of the above figures shows a very great falling off in the quantity exported from Gothenburg, from which it is forwarded chiefly to the English and French and American markets. This diminution is not, however, due to any decreased production, but is owing to the higher prices obtainable of late in the Eastern or Russian market, as well as in the greatly increased home consumption in Sweden.

ON THE DEPTH OF PLATE GIRDERS.

By WALTER R. BROWNE.

From "The Engineer."

It is a well-known theoretical fact that the strain on the flanges of a girder of any kind is diminished as the depth is increased. It is also admitted practically that there is a limit beyond which such increase of depth is not advisable. In large girders this is usually considered to arise from the increased difficulty of stiffening the structure. But in plate girders, large or small, another cause operates to the same effect. This is the mode of calculation always adopted in finding the section of such girders, namely, by considering the whole strain as borne by the two flanges, leaving the web out of the question altogether. Now, if we increase the depth by a constant quantity, the section in the web is also increased by a constant quantity, while that in the flanges is diminished by a quantity that continually lessens, hence there must be a point at which the decrease on the one side is balanced by the increase on the other. Beyond this there will be waste of material in increasing the depth.

To determine the depth, let M be the "bending moment" on the girder, h its depth in inches, E the working strain in tons per square inch, A the area of either flange. Then by the principle of moments,

$$A E h = M.$$

Now suppose that we increase h to $(h+dh)$

then E, remaining the same, we may decrease A to $(A - d\,A)$, and the equation becomes

$$(A - d\,A)\,(h + d\,h)\,E = M.$$

From these two equations we get

$$A\,d\,h - h\,d\,A = 0.$$

Now, if t be the thickness of the web, the increase of metal per unit of length, on changing the depth to $(h + d\,h)$ is $t\,d\,h$, while the decrease in the flanges is $2\,d\,A$. Hence, if these are equal to one another, we have

$$t\,d\,h = 2\,d\,A.$$

But from the above,

$$d\,h = \frac{h}{A}\,d\,A;$$

hence

$$t \times \frac{h}{A} = 2$$

$$t\,h = \frac{2\,M}{E\,h}, \text{ since } A = \frac{M}{E\,h},$$

$$t\,E\,\frac{h^2}{2} = M.$$

In general t may be taken as $\frac{1}{4}$ in., and E the strain per square inch, as 4 tons. Then $t\,E = 1$, and the equation is

$$\frac{h^2}{2} = M.$$

We may now give different values to M.

Case 1.—Cantilever loaded at the end only: Let w be weight in tons, l length in inches; then bending moment, or $M = w\,l$, and the equation is

$$\frac{h^2}{l^2} = \frac{2\,w}{l}$$

Suppose for an example, 8 tons acting at the end of 12 ft. Then

$$\frac{h^2}{l^2} = \frac{1}{9}, \frac{h}{l} = \frac{1}{3} \text{ or } h = 4 \text{ ft.}$$

This is probably a greater depth than could conveniently be given, and thus in this case it will generally be right to make the depth as great as is practicable. If, however, the weight be small, and the length not very small, the limit is easily reached. Thus if $w = 1$, $l = 50$, we have

$$\frac{h}{l} = \frac{1}{5}$$

or the depth should be 10 in., which is less than at first sight one would be disposed to give.

Case. 2.—Cantilever with distributed load: Let w be the weight per inch run; then $w\,l$ is the total weight, which may be considered as acting at the middle point of the length. Hence $M = \frac{w\,l^2}{2}$, and the equation becomes $\frac{h^2}{l^2} = w$. In this case, unless the load be very great, w will be a small fraction, and ratio of depth to length will not be large.

Case 3.—Girder loaded in the middle: This is equivalent to two cantilevers of half the length, and we only have to divide the equation in Case 1 by 4. This gives

$$\frac{h^2}{l^2} = \frac{w}{2\,l}$$

and ratio of depth to length is just half what it was in the former case.

Case 4.—Girder with distributed load: The same reasoning applies here also, and the equation becomes

$$\frac{h^2}{l^2} = \frac{w}{4}$$

In the case of any other distribution of load than these four, the result can, of course, be obtained without difficulty by applying the formula with the correct value of M.

Case 4 being the most common, I subjoin a table, showing the most economical ratio of depth to length in ordinary plate girders, web $\frac{1}{4}$ in. thick, working strain 4 tons, under distributed loads from $\frac{1}{10}$ of a ton (or 2 cwt.) up to 2 tons per foot run of the girder.

Load per foot run.	Ratio of depth to length.	Load per foot-run.	Ratio of depth to length.
Tons.		Tons.	
.1	.045	1.1	.151
.2	.063	1.2	.158
.3	.079	1.3	.164
.4	.091	1.4	.171
.5	.102	1.5	.177
.6	.112	1.6	.182
.7	.121	1.7	.188
.8	.129	1.8	.193
.9	.137	1.9	.199
1.0	.144	2.0	.205

It is to be observed that in the whole of the foregoing the girder has been taken as of the same depth and same flange area through its length. Both these assumptions hold in small girders, but not generally in large ones. There we may have (1) the depth at the ends a fixed quantity, and less than that in the middle. Then the increase of the web following on an increase of depth

is only half that assumed above, and the proportionate depths are too small. (2) The flange area at the ends a fixed quantity, and less than that in the midde; then the decrease of area following on an increase of depth is less than that assumed above, and the proportionate depths are too large. In both cases the correct depth may be found by taking the total increase and decrease respectively, and substituting these for the increase and decrease per unit of length in the equations given above.

ON THE GENERATION OF HEAT DURING THE BESSEMER PROCESS.*

By R. AKERMAN, Professor at the School of Mines at Stockholm.

From "The Journal of Iron and Steel Institute."

Experience has more and more confirmed, that having at hand proper materials for the Bessemer process, there is nothing which exercises so powerful an influence on the quality of the product as the degree of heat which is attained during the process. The greater this heat, the closer and more homogeneous will, as a rule, the Bessemer metal turn out; besides which the danger of its becoming red short is proportionately diminished. Nor does it seem improbable that the brittleness, which at times characterizes Bessemer metal, stands in some relation to a deficiency of heat during the process. Lastly, a good heat will also produce a larger percentage of steel in ingots, partly because a less quantity of material is thrown out by the blast, in proportion as, by the raised temperature, the bath is rendered more liquid, and partly because the metal refined, at a high temperature is sufficiently superheated not to cool in tapping, and thus to form scull. A correct insight into all the circumstances which, during the process in question, affect the degree of heat, must therefore be of the greatest importance to every Bessemer smelter,—the more so that the differences between the kinds of pig iron employed in Bessemer steel making, which arise from the varying qualities of the ores, are sufficiently marked to require very different conditions in different places to attain the desired high temperature.

The wish to contribute, at least in some slight degree to a dissemination of the knowledge, in these respects, which has hitherto been acquired, is the principal motive for the present memoir, which has, however, been more immediately called forth by two dissertations published in the course of last year, namely, Mr. Jordan's in "Bulletin de la Societie des Ingenieurs Civils," and Professor Kupelwieser's, in "Oesterreichische Zeitshrift fur Berg and Huttenwesen," from which papers the substance more essentially bearing on Swedish production will be communicated in the following, conjointly with my own calulations and views.

The object of conversion, as is well known, is to free the iron from the matters with which it is combined in the pig, and which principally consist of carbon (from 2 per cent. to 5 per cent.), silicon (0.1 to about 1.3 per cent. in Sweden, but from 0.3 up to 4 or 5 per cent. in coke pig-iron), and manganese (from traces to about 4 per cent., and in spiegel iron occasionally as much as 20 per cent). The removal of these matters is brought about by their oxidation, which does not, however, take place quite simultaneously, for at the commencement it is, principally at least, the silicon and manganese, together with a small portion of iron, which are oxidized; while in ordinary cases most of the carbon is only removed after the greater part of the two first-mentioned substances has formed a slag.* The silicon and manganese remain even after oxidation, in contact with the iron, forming as silica and protoxide of manganese, together with the oxidized iron, slag; but the oxidized carbon, on the other hand, goes off partly as carbonic oxide, which afterwards, in contact with the air, is further oxidized into carbonic acid.

* Translated from the Minutes of the Institution of Civil Engineers in Sweden, by C. P Sandberg.

* See Calvert and Johnson's investigations of the puddling process, "Annals of the Iron Office, Stockholm, 1858, p. 202," Kollberg on the Bessemer process, "Annals of the Iron Office, 1865, p. 314," and Brusewitz on the same subject, "Annals of the Iron Office, Stockholm, 1871, p. 222."

Conversion by smelting was, up to the year 1855, exclusively effected by the pig-iron—either in contact with charcoal, as in the hearth-forging, or separated from the fuel as in puddling—being smelted down and exposed to the oxidizing influence of the air, as well as of the slag; and in this process no consideration whatever was attached to the generation and consumption of heat which was caused by the chemical reactions taking place in the smelted mass; but in order to obtain a sufficient degree of heat, the simple expedient was adopted of burning separate fuel. The heat engendered by the combustion of this fuel was, however, in by far the greater proportion, entirely lost, partly with the dispersing products of combustion, and partly by the outward radiation from the walls of the furnace; whilst only an inconsiderable portion was brought to act on the iron, partly by its contact with the flame, and partly by the heat communicated to the mass from the furnace walls. In order by this method to smelt down 2 tons of pig-iron in a puddling furnace, and heat it to about 1,400 deg. centigrade, a quantity of about 1 ton of coal was consumed, from which were produced about 7,500,000 calories;* but of these, according to Jordan, 5,000,000 to 6,000,000 were carried away with the gases, and about 1,000,000 were lost by radiation from the furnace walls, while only about 600,000 calories, or say $\frac{1}{12}$ of the heat produced, were absorbed by the pig-iron bath. Now, as regards the fuel which is consumed in the puddling, as well as the charcoal-hearth process, after the pig-iron is smelted, the said fuel is not only entirely wasted by these processes, but a proportion of the heat produced by the oxidation of silicon, manganese, iron, and carbon, which takes place during these processes, is, in point of fact, lost also. The correctnes of this assertion will be best apprehended by a comparison with the Bessemer process, in which with the exception of that possibly necessary for smelting down the pig-iron, no separate expenditure of fuel is required; but the heat generated by that process in itself is so well made use of, that the material or metal remains in a liquid state, and is consequently much more heated than during the puddling process, or process of refining in the hearth.

The Bessemer process consists, as is well known, in forcing atmospheric air through the molten mass of pig-iron; and the cause why the heat generated by this process is so much more completely utilized than in the other converting methods, is simply from the briskness with which the conversion takes place in the Bessemer converter, the whole mass being penetrated by compressed air, and the refining, or oxidation, being consequently effected simultaneously through the whole mass. This "intermolecular" combustion pervading the whole mass of iron, is also the cause of the walls of the Bessemer converter not becoming so superheated as would be the case if it were attempted to bring the mass up to a similar degree of temperature in a reverberatory furnace, because the walls of the Bessemer converter receive the heat, so to say, second-hand from the metal, whereas the contrary takes place in a reverberatory furnace, in which the metal is heated chiefly by the radiation from the roof and walls. It is clear, moreover, that the greater the mass which is manipulated at one time, and the more quickly the process is carried on, the less is the proportionate heat which the walls of a Bessemer conductor will have to absorb and conduct away, and the hotter, in consequence, will be the metal.

Following, principally, Mr. Jordan, we will now, in the first instance, endeavor to explain the conditions of heat which take place during the oxidation of the different substances which enter into the composition of pig-iron, as well with pure oxygen as with atmospheric air, and with so-called "dry" steam at a temperature of 100 deg. centigrade; but before doing this, it will first of all be necessary to put forward certain assumptions in respect of the condition of the pig-iron bath, etc.

According to Pouillet and Péclet, the melting temperature for white pig-iron rich in carbon, is 1,054 deg. C., and for grey pig-iron rich in graphite, 1,200 degs. C. According to L. Rinman, the smelting temperature for ordinary Swedish pig-iron stands at about 1,200 deg. C. Its height of liquefaction, by the same authority,* amounts to 46 calories and its specific heat

between 0 deg. C. and 200 deg. C. to	0.13
" 0 deg. C. and 1200 deg. C. to	0.16
and for molten pig-iron to	0.21

If, therefore, the initial temperature of

* A calorie=3.968 British thermal units.

* Survey of the Transactions of the Royal Academy of Sciences, 1865.

the Bessemer pig-iron bath is assumed to be 1,400 deg. C., or 200 deg. higher than necessary for melting the pig-iron, it would for each ton of pig-iron possess

$$1000\{(1,200\times0.16)\times46\times(200\times0.21)\}=280,000$$

calories; and to change its temperature 1 deg. C. would require the addition or subtraction of 210 calories for the same quantity.

It will be shown, further on in this memoir, that the whole of the oxygen contained in the current of gas injected for converting the pig-iron, is not always completely absorbed by that pig-iron, but that this only takes place under certain conditions; but inasmuch as it should always be the object to try to bring about a complete utilization of the oxygen (because otherwise the metal will become less heated), we will in the following calculations uniformly assume that the oxygen has been fully utilized. It may further be presupposed that the gases passing off from the bath have, in ascending through the latter, absorbed so much heat that, in the main, they leave the bath with its initial temperature, or 1,400 degs. Finally, we will likewise assume that the walls of the converter are perfectly infusible, and that no heat is carried away through them from the bath. These assumptions certainly can never be fully realized, but no essential discrepancies need occur on account of them, inasmuch as this desideratum is approached nearer and near in proportion as larger quantities of pig-iron are converted at the same time, while the process, nevertheless, is accelerated.

In order to make the calculations as easily applicable as possible, they will throughout be made per ton of pig-iron.*

COMBUSTION OF IRON.

1. *With Oxygen.*—For the oxidation or combustion of 10 kilos. of iron, or 1 per cent. of the assumed quantity of pig-iron, there will be required, 8 : 28=2.857 kilos. of oxygen, and the product is 12.857 kilos. of protoxide of iron, in the formation of $2.857\times4,205$† = 12,013 calories are produced.

The whole of this heat cannot, however, be utilized by the iron bath, partly because the protoxide which has been formed decreases the quantity of the metal, and partly because it has a higher specific heat than the metallic iron (0.17 instead of 0.11 in the solid, and probably still more in the molten state), on which account it must deprive the bath of at least

$$\{12,857\times(0.17-0.11)\}1,400=1520$$

calories.

There remain consequently for the additional heating of the bath, per ton pig-iron employed, 12,013 – 1,520 = 10,493 calories for every per cent. of iron burnt with oxygen gas.

2. *With Atmospheric Air.*—For the combustion of 10 kilos. of iron will be required 2.857 kilos. of oxygen, which in the air is accompanied by $\frac{2.857\times77}{23}=9.57$ kilos. of nitrogen. The quantity of heat generated in a ton of pig iron would, as in the previous case, amount to 10,493 calories, were it not that the nitrogen, in ascending through the bath, absorbs and carries away with it $9.57\times0.244\times1,400=3,269$ calories. In this case there will consequently be 10,493 $-3,269=7,224$ calories, which, in every per cent. of oxidized iron per ton of pig-iron, can be utilized for the bath.

3. *With Steam.*—For the combustion of 10 kilos. of iron 2.857 kilos. of oxygen is required, and consequently $2.857\times9:8=3.214$ kilos. of steam, which contains 0.357 kilos. of hydrogen. The quantity of heat generated by the combustion of 10 kilos. of iron amounts, as in the foregoing cases, to 10,493 calories, but if the injected steam has a temperature of 100 deg. C., the amount of heat thus introduced must be added, which makes $3.214\times0.475\times100=153$ calories, so that the whole quantity of heat generated per ton of pig iron by the oxidation of 1 per cent. of the iron in this case amounts to 10,493+153=10,646 calories.

On the other hand, there will be required for the decomposition of the steam $0.357\times29,638$*=10,581 calories, and if the hydrogen set free in the process should escape at a temperature of 1,400 deg., and its specific heat were 3.40, it would carry away from the bath $0.357\times3.40\times1,400=1,699$ calories. The total consumption of heat would, therefore, be 10,581+1.699=12,280 calories. For every per cent. of iron oxi-

* 1,000 kilos. are taken as equal to 1 ton.
† Jernkontoret's Annaler, Stockholm, 1871, page 102.

* The calorimetrical heating effect of hydrogen is commonly set down at 34,462 calories, but for such calculations as the following the condensation or evaporation heat of the water which is formed, say $9\times536=4,834$ calories should be deducted from this.

dized by means of steam there would consequently be a decrease of heat per ton of pig iron equal to 12,280—10,646=1,634 calories.

The diminution of heat, caused by the oxidation of iron with water, cannot in reality, however, be quite so considerable, for in the first place the hydrogen in passing off, cannot carry so high a temperature as 1,400 deg., because in this case the initial temperature of the bath is not increased, but is, on the contrary, reduced; and in the second place it cannot, for reasons which will hereafter be more fully explained, be correct to set down the specific heat of the hydrogen as high as 3.40, inasmuch as this figure represents its specific heat under constant pressure, while its specific heat, at a constant volume, is only 0.2356. Some intermediate value between these two figures would therefore be the right one in this case, but it is difficult to define it, depending as it does on the pressure of the gas in the flue of the furnace, or in the aperture for the escape of the gases from the converter.

Now, if the quantity of heat carried away by the hydrogen is computed on the assumption that its specific heat is only 0.236, and that the hydrogen, when escaping, has only a temperature of 800 deg., the loss of heat here in question would be limited to $0.357 \times 0.236 \times 800 = 67$ calories, and the total consumption of heat would amount to $10,581 + 67 = 10,648$ calories, which at any rate does not fall short of the generation of heat (10,646 calories), from which it is evident that in the combustion of iron with steam a reduction of heat must always take place.

COMBUSTION OF MANGANESE.

The calorific effect of manganese, as far as the author is aware, is as yet unknown, but inasmuch as its equivalent weight not only scarcely differs from that of iron, but also the specific heat of the oxide of manganese very clearly coincides with that of the oxide of iron, it is assumed by Mr. Jordan that the calorimetrical heating effects of these substances must correspond pretty closely. The specific heat of manganese is, however, higher than that of iron, and the protoxide of manganese, in particular, is a good deal more difficult to reduce than the protoxide of iron, and it seems, therefore, on these grounds, to be not altogether unreasonable to assume that the calorific effect of manganese is considerably higher than that of iron. The strongest support for this theory is, however, afforded by the great development of heat which generally distinguishes the treatment, according to the Bessemer method, of such kinds of pig iron as contain any appreciable admixture of manganese; but until the calorific effect of manganese shall have been ascertained by direct experiments, there can, naturally, be no question of calculations as to the quantity of heat generated by the oxidation of that substance.

COMBUSTION OF CARBON.

1. *With Oxygen.*—To convert into carbonic oxide 10 kilos. of carbon or 1 per cent. of the quantity of pig iron taken as a normal, will require $\frac{10 \times 8}{6} = 13.33$ kilos. of oxygen gas. Whether this combustion is effected directly or by indirect action, that is to say, by the oxidation of iron and the reduction again of this iron through the carbon, its result ought, under ordinary circumstances, when combustion, as in the Bessemer process, takes place in a bath of molten iron, to consist in carbonic oxide, for the carbonic acid which may possibly have been formed must be assumed to have been instantly reduced by the molten iron* under the influence of a temperature very highly elevated. Reasons are, therefore, in all probability not wanting for supposing that the quantity of heat generated by the combustion of carbon into carbonic oxide. By the combustion in question there ought consequently, under ordinary circumstances, to be formed 23.33 kilos. of carbonic oxide, resulting in the generation of 24,730 calories.

If the carbonic oxide, when escaping, possesses a temperature of 1,400 deg., it will, however, deprive the bath of

$$\{23.33 \times (0.2479 - 0.241)\}\ 140 = 4718$$

calories, and there will consequently remain $24,730 - 4,718 = 20,012$ calories per ton of pig iron, for every hundredth part of car-

* It has been now long known that the combustion of iron can be effected by means of carbonic acid, and that this faculty of iron to reduce carbonic acid, increases with the degree of heat; but Mr. Bell, in his paper on "Chemical Phenomena of the Iron Smelting," published in the "Journal of the Iron and Steel Institute, 1871," has also shown that this reaction increases more rapidly with the elevation of temperature than the opposite one, or the reduction of oxidized iron by carbonic oxide, and that a jet of carbonic acid, passed over iron sponge at about 400 deg., was so completely transformed into carbonic oxide, that after contact with this iron, the gas consisted of 96 vol. per cent. of carbonic oxide and 4 vol. per cent. of carbonic acid.

bon burnt with pure oxygen, available for the further heating of the metal.

2. *With Atmospheric Air.*—In order to convert 10 kilos. of carbon into carbonic oxide, there is required 13.33 kilos. of oxygen, which, in the atmospheric air, is intermixed with $13.33 \times 77:23=44.66$ kilos. of nitrogen.

The quantity of heat generated by this combustion amounts, as in the case last mentioned, to 24,730 calories, but of these 4,718 calories are carried away with the carbonic acid which has been formed, and $44.66 \times 0.244 \times 1,400=15,260$ calories with the nitrogen, so that there only remains for the heating of the bath per ton of pig iron 24,730—(4,718 + 15,260)*= 4,752 calories for every per cent. of carbon which has been oxidized by means of atmospheric air.

3. *With Steam.*—To convert 10 kilos. of carbon into carbonic oxide 13.33 kilos. of oxygen are required, to produce which it will take 15 kilos. of steam, containing, besides the oxygen, 1,677 kilos. of hydrogen. To decompose this quantity of steam $1.667 \times 29,638=49,407$ calories are absorbed, and if the hydrogen entered at 100 deg., and passed away at 1,400 deg., it would have deprived the bath of $1.667 \times 3.4 \times 1,300=7,367$ calories, so that the total consumption of heat amounts to 49,407 + 7,367=56,774 calories.

The generation of heat, on the other hand, amounts to the same as when the carbon is oxidized with pure oxygen, or 24,730 - 4,718=20,012 calories, to which, in this case, must be added, however, the quantity of heat introduced with the oxyen, consisting of $13.33 \times 0.218 \times 100=290$ calories, so that the total generation of heat amounts to 20,012 + 290=20,302 calories. The quantity of heat taken away from the bath for every per cent. of carbon per ton of pig iron oxidized by steam would, therefore, amount to 56,774—20,302=3,6472 calories.

Were it practicable to estimate correctly the loss in specific heat sustained by the gases in consequence of their condensation, a much reduced value would, no doubt, be arrived at for the decrease of heat in question when narrow funnel apertures are employed; but a comparison with the calculations made in this respect, as will be shown hereafter, will easily indicate that, even if the specific heat of hydrogen were only estimated at 0.2356, and that of carbonic oxide at 0.2399, the combustion of carbon with steam would nevertheless bring about so great a reduction in temperature that the iron could not be kept in a liquid state without an extraneous accession of heat.

COMBUSTION OF SILICON.

1. *With Oxygen Gas.*—For the combustion of 10 kilos. of silicon or 1 per cent. of the assumed weight of pig iron, 24: 21= 11.429 kilos. of oxygen are required.

By this combustion 78,300* calories are produced, but a portion of this heat is consumed in heating the silica which has been formed to a temperature equal to that of the bath. To be able to state how much heat is absorbed for this purpose, it would be necessary to know the difference in specific heat, between silica and silicon; but until this difference becomes known it must suffice to assume the amount of heat in question to be equal to that which is required to raise the temperature of the injected oxygen gas to 1,400 deg., or $11.429 \times 0.218 \times 1,400=3,488$ calories. There remains consequently in this case, per ton of pig iron, for heating the bath, the enormous quantity of 78,300—3,488=74,812 calories for every per cent. of silicon oxidized with pure oxygen gas.

2. *With Atmospheric Air.*—For the combustion of 10 kilos. of silicon, 11,429 kilos. of oxygen are required, which, in atmospheric air, is intermixed with $11.429 \times 77:23=38.261$ lbs. of nitrogen, which, in escaping, deprives the bath of $38.261 \times 0.244 \times 1,400=13,070$ calories.

During this combustion there are, as in the foregoing case, 74,812 calories produced, and for every per cent. of silicon oxidized with atmospheric air the amount of heat in the bath is consequently increased,

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* Neither in this nor in any of the other calculations has any account been taken of the modification caused by the carbonic oxide, as well as the nitrogen, having a greater pressure in the Bessemer furnace than in the surrounding atmosphere. Instead of the specific heat of the carbonic oxide and the nitrogen at constant pressure being respectively 0.2479 and 0.2440, they are, at constant volume, 0.2399 and 0.237, and the quantities of heat carried away by the gases would, with these values attached to their specific heat, be

$$\{(23.33 \times 0.2399 - 0.241)\} 1,400 + (44.667 \times 0.237 \times 1,400) =$$
$$4,462 + 14,828 = 19,290 \text{ calories.}$$

Adopting this opposite extreme, there would remain for heating the bath per ton of pig iron 24,730 - 19,290=5,440 calories for every per cent. of carbon oxidized with atmospheric air.

* The calorimetric effect of silicon is according to Troost and Hautefeuille (Dingler's Journal, vol. 197, page 55), 7,830 calories.

per ton of pig iron employed, by 74,812 – 13,070=61,742 calories.

3. *With Steam.*—To the amount of heat produced by the oxidation of 10 kilos. of silicon, say 74.810 calories, must in this case be added the heat introduced with the oxygen at a temperature of 100 deg., which amounts to 11.429 × 0.218 × 100=24.9 calories. The total generation of heat, therefore, amounts in this case to 74,810 × .249= 75,061 calories. For this the necessary quantity of oxygen is, however, first to be obtained by the decomposition of 12.858 kilos. of steam, which contain 1.429 kilos. of hydrogen, and to effect this decomposition 1.429 kilos. × 29,638=42,353 calories are consumed, besides which, the hydrogen escaping from the bath carries away 1.429 × 3.40 × 1,300 = 6,316 calories. There are consequently consumed in all, 42,353 + 6,316=48,669 calories, so that for heating the bath there remains in this case per ton of pig iron employed 75,061 – 48,669 =26,392 calories for every per cent. of silicon oxidized with steam.

Even assuming the higher value of the specific heat of hydrogen, there arises consequently, in this case, an increase of temperature; but it is very remarkable, however, that this only takes place during the combustion of silicon, for the oxidation of iron, and especially of carbon, by means of steam, produces, on the contrary, a cooling effect. By this, moreover, is also explained the circumstance that the advantages which at times seem to accrue from the use of steam are chiefly experienced at the commencement of the converting process by puddling.

To obtain a more comprehensive view, we will now group together, in one table, the conditions of heat which arise during the combustion, with atmospheric air, of a unit in weight of the principal substances present in pig iron, viz., iron, carbon, and silicon.

The oxidation of 10 kilos. of	Iron.	Calories.	Carbon.	Calories.	Silicon.	
	kilos.		kilos.		kilos.	
Requirements of atmospheric air	12.42	....	47.99	....	49.69	....
Which contains: oxygen	2.85	....	13.33	....	11.43	....
nitrogen	9.57	....	44.66	....	38.26	....
In the combustion are generated	....	12,013	....	24,730	....	78,300
From these deduct the heat which is						
(*a*) carried away with the carbonic oxide	....	....	4,718	....	....	....
(*b*) absorbed by the slag	1,520	....	...	....	3,480	....
(*c*) carried away by the nitrogen	3,269	....	15,260	....	13,070	....
Or in all	....	4,789	....	19,978	....	16,558
For heating the bath there consequently remain, per cwt. of pig iron employed, for every per cent. of the respective substances which has been oxidized	....	7,224	....	4,572	....	61,742

With reference to this table it should, however, once more be observed, in the first place, that the specific heat of the gases has been calculated as if the gases had always had the opportunity of free expansion, or, in other words, as if their pres ure had been equal to that of the exterior air, and in the second place, that no account has been taken of the heat conducted away and radiated by the walls of the furnace; also that the products of combustion have been assumed to pass off from the bath at the same temperature as the latter was considered to possess at the commencement of the process, viz., 1,400 deg. C.

Messrs. Jordan and Kupelweiser assume, as before intimated, the caloric effect of manganese to be the same as that of iron, and do not, therefore, ascribe to the manganese contained in Bessemer pig iron any beneficial influence on the heating process. In as far as the temperature depends on the composition of the pig iron, they consider, in accordance with the calculations here imparted, that it is virtually determined by the proportion of silicon present in the pig-iron bath, which, to produce a certain degree of heat, should amount, it is estimated, at the very least to 1.25 per cent.

The figures presented above appear in fact to make it clear that the charge must become more heated the more silicon is contained in the pig iron, provided only that the blast is strong enough to allow the process to be completed with sufficient rapidity, notwithstanding the presence of

a larger proportion of silicon,* and also that the bath is deep enough for the complete utilization of the oxygen in the blast, even if by reason of the increased proportion of its silicon the pig iron should have become less disposed to absorb oxygen, of which tendency we shall have more to say further on. But even admitting this powerful action of silicon in generating heat, it in nowise follows as a necessary consequence that the presence of manganese may not exercise a much greater influence on the generation of heat in the Bessemer process than Messrs. Jordan and Kupelweiser have assumed. That such is indeed the case seems to be demonstrated by the experience acquired at one or two Swedish Bessemer works, and as a proof of this it may suffice to state that at one of the said works, where the pig iron usually contains nearly 3 per cent. of manganese, but only the inconsiderable portion of 0.7 per cent. of silicon, the charge generally seems to have a higher temperature than at most other Bessemer establishments. It is by no means to be inferred from this, however, that the charges at the works in question might not be still hotter if the force of the blast-apparatus would allow of a greater proportion of silicon in the pig iron; but under all circumstances it seems to follow as an undoubted consequence that in this respect the presence in the Bessemer pig iron of a proportion of manganese up to as much as 3 per cent., must be very desirable. Whether this, on the other hand, is particularly advantageous as regards the final result is a matter which cannot probably be so unconditionally affirmed; for a Bessemer pig iron holding much manganese will sometimes produce a steel very much impregnated with that substance, and there are, at any rate, not wanting reasons for supposing that steel, as well as iron, holding a considerable portion of manganese, will be more sensible to concussion than those metals more free from manganese, and that the presence of manganese increases the tendency to crack, and causes the iron to act with a greater corrosion on the moulds. Be this as it may, however, it is a fact that most of the Swedish blast furnace charges are not in any appreciable degree impregnated with manganese; and at such places where the Bessemer process is to be adapted to charges so impregnated, it is all the more necessary, in order to obtain a hot charge, that the blast apparatus should have sufficient force* to enable the operator to employ a pig iron tolerably rich in silicon.

As long as the calorimetric heating effect of manganese remains unknown, it is plain that it cannot be stated, in exact figures, how much heat its combustion furnishes to the Bessemer process; but, on the other hand, the amount of heat available for the bath when a pig iron free of manganese is treated according to the said process, can always be easily computed, with the assistance of the calculations shown in the foregoing, provided only that it can be demonstrated what quantity of each particular substance is oxidized in the process.

Messrs. Jordan and Kupelweiser estimated these quantities in a normal Bessemer process at 2 per cent. of silicon, 4.25 per cent. of carbon, and 8.75 per cent. of iron; but, as corresponding more closely with the condition of our Swedish iron manufacture, I will assume them to be

1.00 per cent. silicon
4.25 " carbon
6.00 " iron

There would in this case be available, per cent. of pig iron employed, to increase the temperature of the bath during this process:

1.00×6174.2=6174.2 calories.
4.25× 475.2=2019 6 "
6 00× 722.4=4334.4 "

Total..... 12,528.2 "

The specific heat of molten iron is as yet not known; but as in the case of molten pig iron, it is about 50 per cent. higher than that of pig iron from 0 deg. to 200 deg., and as the specific heat of iron at the usual degree of temperature is 0.11, the specific heat of molten iron may be set down at about 0.16. The temperature of the bath would in consequence be increased, during the process, to the extent of 12,528 : 16= 783 deg., and as its original temperature was 1,400 deg., the final temperature would, in that case, be about 2,200 deg. As no method has hitherto been invented by which such high degrees of temperature as those just mentioned can be measured, it is obviously impossible to know for certain how nearly this estimated degree of heat coin-

*See "Illustrated Technical Journal," Stockholm, 1871, page 107.

*See "Illustrated Technical Journal," Stockholm, 1871, page 115.

cides with the real fact; but that the figure derived from the said calculations cannot be far from the truth seems to be established by Kupelweiser's observations on the fusibility of platina in molten Bessemer metal. During his experiments at Heft, he found that a tolerably thick piece of platina wire, inserted in the jet of soft iron running out from the Bessemer furnace, was fused in a few seconds, but when a little specular iron had been added to the ladle, and the steel had been run into the moulds, a platina wire inserted in the still perfectly liquid metal was not fused at all. As the degree of heat requisite to fuse platina is, according to the investigations of Sainte Claire Deville, below 1,900 deg., it would appear that the temperature of 2,200 deg. assigned to the Bessemer iron, on completion of process, has much probability.

In the foregoing has been shown what influence is exercised by the composition of the pig iron on the amount of heat generated in the Bessemer process, but the temperature attained is not, however, exclusively dependent on this and on the specific heat of the bath, but also on the time required for the combustion, inasmuch as the loss of heat by external cooling must be greater in proportion as the process is protracted. It is, therefore, not enough that certain percentages of the substances entering into the composition of pig iron undergo combustion during the process, for unless a considerable portion of the heat generated thereby is to be wasted, the combustion must, besides, be effected with great rapidity; but for this purpose an abundant supply of blast is necessary, a supply which cannot be procured except by a powerful blast apparatus.*

The degree of heat imparted to the walls of the furnace before the introduction of the pig iron will also considerably influence the cooling which takes place through radiation from the said walls, besides which it is evident that the amount of heat lost per weight unit of pig iron through the walls must be less in proportion as the quantity of pig iron under treatment is increased, for if the furnaces are properly constructed the surfaces of their walls will not be augmented in a ratio proportionate to the space within, from which it follows that the loss of heat will be comparatively less in working with greater charges.

In the calculations of heat hereinbefore specified, no account has been taken of the cooling through the walls just mentioned, and as this cooling cannot be entirely prevented, even with the best heated furnaces and the heaviest charges and the greatest acceleration of the process, it is evident that the conclusions as to temperature mentioned above must be a little too high, unless the cooling in question may be compensated by the circumstance that, on the other hand, no account has been taken of the rise in temperature which must be caused by the gases leaving the furnace under a pressure depending on the size of the nozzle, but more or less exceeding that of the atmospheric air.

When gases expand it is known that they absorb heat, which is again liberated on their being condensed in a corresponding degree. It is evident, therefore, that the higher the pressure sustained by gases on their escape from a furnace, the less heat do they carry away with them, and the higher, consequently, will the degree of temperature in the furnace be, other conditions being assumed to be equal. From this it follows that the narrower the aperture is for the escape of products of combustion from a Bessemer furnace, the hotter the charge must be, provided always that the blowing apparatus has force enough to be capable of pressing in the same quantity of air, notwithstanding the increased resistance, so that the process is not retarded by reason of the contracted aperture of the nozzle.

As already stated, no account has been taken in the foregoing calculations as to heat, of the rise in temperature occasioned by the circumstance just adverted to; but owing to the difficulty of determining which of the figures comprised between the two extreme limits denoting the quantities of specific heat (for constant pressure and constant volume) may be the correct ones, they have, in accordance with M. Jordan, simply been estimated at the same degrees as if the gases, in escaping from the Bessemer furnace, had only the pressure of the surrounding atmosphere. That component part of the pig iron, the calorific action of which, during combustion with atmospheric air, has the least justice done to it by this estimate, is the carbon, inasmuch as the combustion of this substance produces the

* Respecting the basis of calculation of the force required for the blast of the Bessemer furnace, see article in the "Illustrated Technical Journal," Stockholm, cited in a previous note.

greatest quantity of gas; but in order to indicate the limits within which the error thus committed must lie, it has been explained in a foot-note how the result would turn out if it could be allowed to compute the specific quantities of heat in the gases as low as in their state of constant volume.

The calculations of heat presented in the foregoing are based on the assumption that during the rising of the atmospheric air through the Bessemer bath, the whole of its oxygen is completely utilized, so that only the nitrogen contained in the blast, but no part of its oxygen, escapes from the bath in a free form. If, on the other hand, the oxygen should not be completely absorbed by the metal, a loss of heat will be the natural consequence; in the first place because the generation of heat in a certain moment of time is diminished in the same proportion as the utilization of oxygen is lessened, or the refining process retarded; and in the second place, because the free oxygen, just like the nitrogen, absorbs heat, which escapes, without profit, with the oxygen from the furnace. The waste of produce, moreover, will also be somewhat increased by this, because the gases which fill the furnace are, in this case, oxidized, and, therefore, in their turn, oxidize a portion of the iron bubbling at the surface, partly converting it into oxide of iron, which is not retained in the slag, but escapes as a reddish-brown smoke with the gases.

If the air is forced too quickly through the bath the latter will not have time to absorb the whole of the oxygen, and the more or less complete utilization of that substance by the same description of pig iron, depends, in consequence, on the time occupied by a particle of air in ascending through the bath. Again, the time of contact between the metal and the blast is increased with the depth of the bath, but decreases with the pressure of the blast, and it is clear, therefore, that already, on this account, the depth of the bath and the pressure of the blast must be made in some measure to correspond. Furthermore, it is hereby made equally clear that in a cupola converter with vertical tuyeres placed at the bottom, so shallow a bath cannot be profitably employed as will be practicable in a Bessemer converter with horizontal tuyeres, for in the first-mentioned description of converter, the blast goes the nearest way straight up through the bath, while in fixed converters, on the contrary, it must describe a curved line, chiefly depending as to extent on the pressure of the blast and the depth of the bath. Even in a cupola converter, however, the depth of bath need probably not require to be increased in full proportion to the blast pressure, for the stronger this pressure is, or the harder the blow of the blast, the more intimate should the contact become between the air and the particles of iron, and the more easily would, therefore, the metal be enabled to absorb or utilize the oxygen.

The absorption of oxygen does not appear, however, to depend exclusively on the circumstances hitherto dwelt upon, but just as different descriptions of pig iron at their tapping from the blast furnace already show different dispositions for being oxidized, some of them sparkling or burning a great deal more than others,* so it has, in like manner, appeared at the Swedish Bessemer works, as if Bessemer pig irons of different compositions were more or less ready to absorb oxygen; a grey pig iron seeming to require a longer period of contact between the particles of air and iron and a stronger blast pressure, for a complete absorption of the oxygen of the blast, than a less grey or white iron. It is therefore necessary, in order completely to utilize the oxygen of the blast, to increase the depth of the bath in proportion to the quality of the pig iron. In the contrary case, or if while employing a more than usually grey pig iron, the depth of the bath should be made as shallow as could possibly be compatible with the absorption of the oxygen by a whiter, or No. 3 of pig iron, it would, in most cases, happen during the first so-called refining or slag-forming period, that the before-mentioned reddish-brown smoke which is produced by an incomplete utilization of the oxygen, would make its appearance, accompanied, moreover, and from causes explained above, by a decrease of heat in the process.

Although, under usual circumstances, the silicon is mostly oxidized before the carbon, or during the slag formation period, while the

* The difference in degree of temperature of the pig iron exercises, no doubt, in this respect a very material influence, causing the warmer of two otherwise similar descriptions of pig iron to burn fiercer than the cooler of the two; but it is a known fact, that even if the temperature is the same, two different classes of pig iron may exhibit a very dissimilar disposition to burn or throw sparks while running out from the blast furnace.

combustion of the carbon principally takes place during the boil and the after-refining, it is nevertheless probable that the chief cause of a lessened disposition in pig iron to absorb oxygen will be found in the larger proportion of silicon which it contains. It has already been shown in the foregoing, that the richer in silicon the Bessemer pig iron is, the hotter will the charge become, provided that the greater admixture of silicon does not retard the process too much, nor prevent a complete utilization of the oxygen of the blast. But in order that these conditions may be fulfilled, it is again evident from the reasons above given, that the more grey and the more rich in silicon is the pig iron to be operated upon, the more abundant must the supply of blast be, and, in consequence, the greater is the force required; the more so as a very dark and graphitic pig iron usually is comparatively thick-flowing, and consequently offers greater resistance to the blast.

One foot is considered about the ordinary depth of bath for the Bessemer vessel. Less than that would hardly suffice to insure proper success when making use of a moderately hard pig iron free from manganese, and a pretty considerable blast pressure.

Having thus, in general outline, touched on the usual circumstances which produce more or less heat in the charge of a Bessemer furnace, we will now, in conclusion, endeavor to ascertain also what influence, in this respect, may be expected from sundry projects, either already essayed in some place or another, or altogether untried, to obtain sufficient heat in the Bessemer process, even with a No. 3, or white pig iron.

As, generally speaking, no separate fuel is employed in the Bessemer process, it readily suggests itself to try the use of such fuel for raising the temperature in this process as in others. With this view experiments were commenced at Neuberg as early as the year 1867, to inject charcoal dust with the blast,—a procedure which is said to have been afterwards generally continued at that place, and likewise to have been tried, at least at intervals, at some other Bessemer works. That the degree of heat will be somewhat increased hereby is natural; but it is equally obvious that if the process is to be finished off with the same rapidity when charcoal dust is being injected as when it is not, the supply of blast must be more abundant than otherwise, inasmuch as part of the air is consumed for combustion of the injected charcoal. The main question is, however, whether the charcoal employed in this manner is utilized to greater or less advantage than if it were used in the blast furnace to produce a more grey, or No. 1 pig iron.

As has been already shown, the combustion of 10 kilos. of the carbon of the Bessemer bath, with atmospheric air, produces an increase in heat of 4,752 calories; but the injected charcoal dust does not possess the same temperature as the carbon contained in the pig iron. It must first be heated up to that point in the bath, for which purpose $2.4 \times 1{,}400 = 3{,}360$ calories are consumed, and the accession of heat obtained by combustion of 10 kilos. of injected charcoal dust is consequently reduced to $4{,}752 - 3{,}360 = 1{,}392$ calories, which would scarcely suffice to raise the temperature of 1 ton of molten iron 9 deg. Were the object, therefore, by the injection of charcoal dust, to make up for the heat generated by a portion, say 0.5 per cent. of silicon contained in the pig iron, it would be necessary, inasmuch as the combustion of 0.5 per cent. of silicon increases the heat of the Bessemer bath by $61{,}742 \times 0.5 = 30{,}871$ calories, to inject $30{,}871 : 1{,}392 = 222$ lbs. of pure carbon, or nearly 5 barrels of charcoal for every ton of pig iron.

As, moreover, Professor Kupelweiser has made the observation that a portion of the charcoal dust has not, in point of fact, the time requisite to be consumed in the metallic bath, but that its combustion is first effected outside of the neck of the retort, it seems to be clear that the action of so inconsiderable a charcoal injection as it is customary to make at Neuberg, or 3 to 5 per cent. of the weight of the pig iron, cannot produce any very appreciable effect; in full confirmation of which, Herr Kupelweiser has also stated that it can scarcely be discerned by impartial investigators. It further follows from this that it can hardly be in accordance with good economy, as long as cold blast is used, to substitute an injection of charcoal dust into the Bessemer furnace for the consumption of charcoal which would be requisite to produce in the blast furnace a pig iron sufficiently grey to obtain by it a high degree of heat in the Bessemer process, especially as such can be produced without any additional consump-

tion of charcoal, if only the stove is powerful enough to supply the blast furnace with a higly heated blast.

A plan, advocated by Messrs. Styffe and Tunner, to raise the temperature in the Bessemer process, is to employ heated blast, and a prize of 1,000 florins has been offered in Austria for a successful realization of this idea.

Having regard to the great amount of blast power required for the Bessemer process, and to the considerable quantity of gases which in a highly heated state escapes from the furnace, it is not difficult to conceive that the heating of the blast ought to insure material advantages; but for this purpose it is necessary that the blowing apparatus shall be sufficiently powerful to be able, notwithstanding the attenuation of the air caused by its higher temperature, to force in so large a volume of it that the process may be completed with the requisite rapidity.

If the additions of heat, which are supplied to the Bessemer bath by combustion with atmospheric air at different degrees of temperature of 10 kilos. of iron, carbon, and silicon, are calculated in the same manner as has previously been done with unheated blast, and if the specific heat of oxygen is assumed to he 0.2182, the following quantities of heat will result:

	Deg. Temp.	Of 10 Kilos. of Iron.	Of 10 Kilos. of Carbon.	Of 10 Kilos. of Silicon.
		Calories.	Calories.	Calories.
With blast of.....	0	7,224	4,752	61,742
" "	100	7,520	5,133	62,925
" "	200	7,816	7,514	64,100
" "	300	8,112	8,895	65,291
" "	400	8,408	10,276	66,474
" "	500	8,704	11,657	67,657
" "	600	9,000	13,038	68,840

The greater the quantity of oxygen required for the combustion of any given substance, the greater will naturally be the accession of heat obtained from the heating of the air by that substance. Consequently the accession of heat obtained, by heating the blast, is comparatively greater from the carbon then from either of the other substances.

Let us now see what accessions of heat would be produced with blasts of different temperatures per ton of such Bessemer pig iron that in conversion there would be oxidized at a blast temperature.

	Of 0°.	Of 100°.	Of 200°.	Of 300°.	Of 400°.	Of 500°.	Of 600°.
	calories.	calories	calories.	calories.	calories.	calories.	calories.
1.00 per cent. of silicon	61,742	62,925	64,108	65,291	66,474	67,657	68,840
4.25 " " carbon	20,196	26,065	31,934	37,804	43,673	49,542	55,411
6.00 " " iron ..	43,344	45,120	46,896	48,672	50,448	52,224	54,000
	125,282	134,110	142,938	151,767	160,595	169,423	178,251

These accessions of heat would—if the specific heat of the molten iron is assumed to be 0.16, and no account is taken of the slag which had been formed—for the several degrees of temperature of the blast correspond to the following increments in the temperature of the bath:

Degrees.					
783	838	894	948	1,004	1,059	1,114

It is clear, therefore, that if the bath of Bessemer pig iron, in order to attain a sufficiently high degree of temperature, only requires the accession of a certain amount of heat, it is possible to employ in the Bessemer process, without detriment, a pig iron less grey in proportion as the temperature of the Bessemer blast is raised. In this manner it is easy to calculate that, with a blast heated to 500 deg., there should not be required a greater proportion than 0.35 per cent. of silicon in the pig iron, to obtain as great a heat during the process as can

be produced with a pig iron containing 1 per cent. of silicon when the blast is not heated. But, as has been stated above, it is necessary for this purpose that the blast apparatus should be so powerful that the conversion with heated blast can proceed as rapidly as with cold; and if to this is added, first, the circumstance that the loss of heat in a Bessemer heating apparatus must be very considerable in places where the intervals between the blowings are so long, as is usually the case with us in Sweden, and then and principally the increased difficulty which undoubtedly arises from the heating of the blast, to keep the tuyeres in proper order, it may perhaps still be a question whether it will not be cheaper, when the injection of charcoal dust is not simultaneously resorted to, to procure with the assistance of powerful heating apparatus for the blast furnace, and without extra consumption of charcoal,* a sufficiently grey or No 1 pig iron, to be able to dispense with the Bessemer blast heating apparatus.

If, on the other hand, the Bessemer hot blast can, in some way, and without the too rapid destruction of the tuyeres, be combined with the injection of charcoal dust, its action ought, as was first pointed out by Kuppelweiser, to be very powerful; and it would even appear as if in that case a pig iron, almost as poor in silicon as that used for refining in the charcoal hearth process, might be employed with advantage in the Bessemer process. For 10 kilos. of charcoal burnt in air heated to 500 deg. would increase the heat of the Bessemer bath by 11,657 calories, while 3,360 calories would be required to heat the charcoal from 0 deg. to the initial temperature of the bath; and the accession of heat produced by 10 kilos. of charcoal would therefore, in this case, amount to 11,657—3,360=8,297 calories. The quantity of heat infused into the Bessemer bath by the combustion of 0.5 per cent. of silicon with cold air, might, therefore, when the blast is heated to 500 deg., be indemnified by the injection $0.5 \times 61{,}742 : 8{,}297 = 37$ kilos. carbon, or about 0.7 of a barrel of charcoal per ton of pig iron. To arrive at a correct estimate of the effect produced by the Bessemer hot blast in combination with the injection of charcoal dust, it should be observed, in conclusion, that in the calculation last made no account has been taken of the influence which the heating of the blast to 500 deg. in itself exercises on the temperature of the bath; but about this something had been said previously.

Another method of raising the temperature in the Bessemer process would be to inject oxygen gas; but in regard to this the question arises, whether such gas can be procured at so low a cost that its use would bring any advantage; and in order to estimate this, we will, in the first instance, examine how great the accession of heat to the bath would be if the conversion were effected with pure oxygen:—

		Calories.	
10 kilos. silicon	in combustion with unmixed oxygen increases the heat of the bath with	$1.00 \times 74{,}412$	= 78,812
42 5 " carbon		$4.25 \times 20{,}012$	= 85,051
60.0 " iron		$6.00 \times 10{,}493$	= 62,958
			222,821

The amount of heat generated by the oxidation of the above assumed quantities of silicon, carbon, and iron, would therefore be sufficient to raise the temperature of the bath nearly 1,400 deg.; and even if all the heat proceeding from the silicon were deducted, the bath ought consequently, when converted with oxygen, to be 100 deg. hotter than has been considered necessary for an average temperature of the process. The use of unmixed oxygen, however, could hardly come into question, but if employed, it would probably be in an admixture with atmospheric air; and if, in order to ascertain the value of oxygen in this respect, it is desirable to investigate, for instance, how much extra oxygen would have to be mixed with the air to produce the same increase of temperature in the refining of the pig iron above treated of as would result without an extra admixture of oxygen, by heating the atmospheric air to 500 deg., it will be found that for this purpose the air must be mixed with barely 19 per cent. of its weight, or 17.3 per cent of its volume of oxygen. The nitrogen present in unmixed atmospheric air takes away from the bath, for every ton of pig iron 222,821—125,282=97,539 calories, which loss of heat, if the temperature of the bath is to be the same as when a blast heated 500 deg. is employed, must be brought down to 222,821—169,423=53,398 calories. But in order to make this possible the

* See the "Annals of the Iron Office, Stockholm, 1871," p. 268.

quantity of nitrogen per ton of pig iron must not exceed 53,398 : (0.244×1400)= 156.32 kilos., which is contained, together with 46.68 kilos. of oxygen, in 202.9 kilos, or 2,536 cubic ft. of atmospheric air, while for the said purpose are required 370.6 kilos., or 4,630 cubic ft. of unmixed air at 0 deg. temperature and a medium barometric pressure, to which the quantities of air and oxygen are here always reduced. To oxidize the stated proportions, per ton of pig iron, of the several constituents of the pig iron, requires in all, 85.24 kilos. of oxygen, of which consequently in the case before us, 85.24—46.68=38.56 kilos., or 440 cubic ft. per ton of pig iron, must be intermixed with the atmospheric air.

That an entire or partial exchange of the Bessemer blast for steam would not be attended by a higher, but, on the contrary, by a considerably lower temperature than when air alone is employed, can be easily gathered from the calculations presented at the beginning of this memoir, inasmuch as they show that in Bessemer refining with steam it is only the silicon that, in being oxidized, affords any accession of heat, while the oxidation, as well of the iron as especially of the carbon, on the other hand, is attended with a positive lowering of the temperature. As the silicon is chiefly oxidized during the commencement of the process, it is only at that stage, or during the refining period, that there should ever be any question of injecting steam, and the object of so doing would in that case be to eliminate sulphur in some degree; but even at this stage the introduction of steam will produce a less elevation of temperature than would have been attained by the injection of a corresponding quantity of air.

It has also been proposed to inject, through concentric double tuyeres, air and hydrogen, to form water by combustion, and thus produce an increase of temperature; but the water which is formed in this way would, in ascending through the bath, be again decomposed, and thereby absorb just as much heat as was engendered by its formation. The consequence of such an arrangement could, therefore, hardly be any other than a cooling proportionate to the injection of hydrogen, for no heat can very well be generated by the hydrogen in such a manner. In fact, the latter will in this case rather compare with nitrogen, and will, like that gas, while rising through the bath, absorb heat and then carry it away from the furnace; while, on the other hand, the only heat engendered would have been produced by the injection of air alone.

THE GUNPOWDER PROBLEM.

"From the Engineering and Mining Journal."

It has long been known that the chief difficulty to be overcome in the construction of large cannon results from the fact that the destructive effect of gunpowder increases, when we enlarge the calibre, much more rapidly than the restraining power of the gun. An enlargement of the calibre implies an addition to the weight of the projectiles and of the charges of powder; and not only is the total effect increased, but also its relative intensity; that is to say, not only is the number of sq. in. increased upon which the expanding gases act, but the intensity of the pressure per sq. in. is also augmented. When the necessity for larger guns became imperative, European constructors supplanted cast iron with wrought iron and steel, and thus succeeded in increasing the strength of their guns to the required degree. But when the progress of naval construction called for still greater ballistic power, even this resource began to show signs of inadequacy. In the meantime, the same problem had to be solved by American constructors, who approached it in a different manner. As this country possessed no workshops or machinery adequate to the forging of very large cannon, instead of endeavoring to build guns which powder could not destroy, our officers endeavored to obtain a powder which would give the necessary velocity to the projectiles without destroying the gun. This course was first marked out by Rodman, when he built his famous 15-inch gun. Foreseeing that unless he could maintain the velocity of the projectiles, the increased size would be of insufficient advantage to compensate its inconveniences, he applied himself to the study of the action of gunpowder. His first result was the establishment of "mammoth" or large-grained powder for the

service of large guns. He demonstrated that by this device the velocity of large projectiles could be maintained with a great reduction in the destructive effects of the powder. This identical device has, within the last three years, been adopted by the English for all their large guns under the name of "pebble powder." Although this powder was introduced into our service prior to 1860, the English appear to regard it as an innovation originating in their own country. The value of priority in the matter is, however, much diminished by the fact that the effect of varying the size of the grain, has been known, in a general way, in all countries, for many years, and perhaps for centuries; and the mammoth powder is merely an extreme case in the application of an old principle. But the first accurate and available determinations and measurements of these effects are due entirely to Rodman.

This distinguished officer made a number of brilliant inventions, in which he displayed the rare and double merit of elucidating principles and originating ingenious devices for making them available. A striking illustration of this is his invention of perforated powder, which was made by pressing the materials, in a moist and adhesive condition, into the form of hexagonal prisms, with perforations parallel to the axis. While experiments were progressing with this powder, an eminent Russian officer, Major (now Major-General) Gadolin, being in this country, and taking much interest in the subject, recommended its trial in Russia, and the result was its adoption, first, by the Russian, and afterwards by the Prussian Government, in whose heavy guns it is now used exclusively. The principle involved may be briefly stated. While the shot is moving from its seat to the muzzle, and acquiring its velocity, the force of the powder is undergoing great and rapid changes of intensity. This intensity is known to reach its maximum, with ordinary powders, before the shot has moved a foot from its original seat. The pressure then falls off rapidly as the shot moves towards the muzzle. It is these earlier pressures which are so dangerous, while the later ones are far within the limit of pressure which the gun is capable of enduring with safety.

Not, if it were practicable to manage the powder in such a manner, that the earlier pressures would be reduced, and the later ones increased; the total force would be the same, while the dangerous pressure would be avoided. Rodman sought to attain this action by the following means. It is clear that the pressure at any moment has a direct relation to the quantity of gas developed by the powder in its progressive combustion; and again the quantity of gas developed at any moment has a direct relation to the quantity of powder surface undergoing combustion at any moment. Hence, if the surface of a given weight of powder be small, the quantity of gas at first developed, and the consequent early pressure, will also be small. If the powder, in other words, can be made to burn less rapidly at first, and more rapidly afterwards, the desired end may be reached. Since large-grained powder presents less original surface than an equal weight of small grain, this object is in some degree approached by mammoth powder. A further approximation is obtained by the prismatic form; for the large, symmetrical grains present, at first, a comparatively small surface, while the perforations are constantly increasing their diameters and surfaces, as the grain is consumed.

Recent experiments with the thirty-five ton Woolwich gun have shown, that even mammoth powder is too violent for guns of this size. This conclusion was reached in this country several years ago, after the bursting of several large rifles firing this grade of powder. Within the last two years the Ordnance Bureaux both of the Army and Navy have recognized, that it is indispensable to further progress to gain a more thorough control over the energy of gunpowder than has been yet reached by other nations, and with this view have applied themselves vigorously to the problem. The results thus far attained have not been made public, but are said by those who know, to be peculiarly gratifying.

The navy bureau is experimenting upon powder for the 15-inch gun, while the army bureau is firing heavy rifles, and both have succeeded in obtaining high velocities with unprecedented low pressures. We understand that some new and important features have been introduced, but we are not informed as to their character. The experimental powder has been manufactured by Messrs. Dupont & Co., of Wilmington, who are entitled to the highest credit for their intelligence and zeal, as well as for the excellence of their products. The important nature of these investigations may be infer-

red from the remark recently made to us by a distinguished officer engaged in them, who said that if the results continue to be what they have been, we shall be able to obtain, with perfect safety, from cast-iron guns of the largest calibre, higher velocities than have ever yet been reached with similar calibres elsewhere. During the coming year, these experiments will be diligently prosecuted.

INTERNATIONAL TONNAGE.

From "Naval Science."

It has long been recognized that a uniform international system of tonnage measurement would be a considerable benefit to all classes of persons interested in shipping, whether as owners, freighters, or builders. The delays and annoyances caused by the frequent re-measurements of foreign ships in English ports, and *vice versa*; the importance of fairly apportioning the charges for such cosmopolitan works as the Suez Canal and the preservation of the channels at the mouth of the Danube; and the uncertainty as to what the tonnage of a foreign ship (even when a sailing ship) may mean as to her capacity for cargo, are all cogent reasons for the adoption, not merely of a common unit of tonnage, but of a fair and complete common system of measurement. A few years ago a table of the equivalents in English tons, of the official measurements of ships, used by the several maritime nations, variously expressed as tons, lasts, etc., was compiled for the use of the Danubian Commission in the assessment of dues upon shipping. This, although useful as a comparison of the average tonnages, cannot be depended upon for giving even an approximation to the carrying capacity of any particular ship, seeing that the methods of measurement in use in any foreign countries are as uncertain and inequitable in their operation as was the old law of "builders' tonnage." The inconvenience of this state of things appears to be at last in course of removal by the adoption of the English system of measurement by the several maritime nations. Its recommendation for general use was implied by a clause of the "Merchant Shipping Act Amendment Act" of 1862, in which it was provided that when any foreign nation adopts the English system of tonnage, ships of that nationality shall not be measured in any British port, but shall be assessed for light and harbor dues, etc., upon the figure recorded in the ship's own papers. The invitation thus given has been responded to by four maritime powers—by Denmark and the United States in 1868, by Austria in 1871, and now by Germany, who have all accepted the English rules to such an extent as to enable our Government to apply to them the reciprocity clause of the Act of 1862, although their tonnage laws are not identical with ours, for reasons which will presently be shown. As the question stands at present, nearly one-half of the foreign ships which visit the ports of the United Kingdom belong to nations which have adopted English tonnage. The purpose of this article is to describe in its main features the English tonnage system, contrasting it with the rules in force in other countries, as well as with some other methods of measurement which have at various times been proposed; and at the same time to state some of its acknowledged defects, which, owing to the pressure of other Parliamentary business, have not yet been remedied.

All tonnage rules at present in force are ostensibly measurements of *space*, not of weight; the English rule differs from most others in being an accurate and fair, instead of a loose and inequitable, measurement of space. Its first principle is to assess ships in proportion to the cubic content of the closed-in space available for cargo and passengers, and as stores cannot be well distinguished from cargo, store spaces are included in the measurement. Deck cargoes are not charged for, because a ship's whole loading must be exceptionally light to enable her to carry much upon her deck with safety, while, on the other hand, empty space is often included in the assessment, because, by virtue of its buoyancy, it affords the means of carrying heavy cargo. Space occupied by passengers is also charged for, as being equally profitable with that used for freight. A commission appointed in 1849 to consider the tonnage laws proposed that the assessment of ships should be based upon their entire cubic content,

and put forward a very elaborate method of external measurement, which, however, was unfavorably received by shipbuilders, and was consequently not adopted by the Government. External measurement was evidently open to the grave objection that an advantage would be given to ships of small scantling, and thus the building of slight, fragile vessels would be encouraged. In addition to this, it was objected that ship measuring would become an intricate process, necessitating the employment of a large staff of professional draughtsmen, and could only be performed when the ship was in dry dock or aground. Under the present tonnage rules of internal measurement the required dimensions can be taken whether the ship is ashore or afloat, and by Custom House officers, under the supervision of a very small professional staff.

The English law of gross tonnage provides, as we have said, for accurate measurement of the various portions of the interior of a ship, whatever her form may be. The space under the tonnage deck (the second deck from below in ships with more than one deck) is measured thus:—The exact internal length is taken at a distance below the deck equal to one-third the round of beam, and divided into a number of parts, varying with the size of the ship, from four to twelve. At each point of division a transverse sectional area is measured; the depth being taken from the ceiling (average thickness only being allowed in all cases) to a point distant from the under surface of the deck by one-third the round of beam, and divided into four or six parts, as it is below or not below sixteen feet. At each division of the depth, and at its upper and lower extremities, breadths are measured. The areas of the transverse sections, and from them the cubic content of the hold, are obtained by the well-known rule deduced from the expression for the area of the common parabola. The experience of eighteen years has shown that the depths and breadths are measured near enough together to prevent all possibility of nipping the form of the ship between them, and the minutiæ of measurement are so carefully defined that no advantage can be gained by any exceptional arrangement of ceiling or platforms. Spaces between decks, houses upon the upper deck, poops, etc., are measured by breadths taken at the middle of their height; these, with the interval of length, are put in Simpson's rule, the area of the longitudinal horizontal section at half the height thus obtained. This area multiplied by the height gives a sufficiently near approximation to the cubic content. In all these cases the measurements are taken in feet; and the content, in cubic feet, is divided by 100 for the tonnage. The measurement is also, by a recent arrangement, recorded on the ship's papers in cubic metres as well as in tons, one ton being taken to be equal to 2.83 cubic metres. In Austria and Germany the measurements are taken in lineal metres, and the content (in cubic metres) multiplied by .353 for the tonnage, and in Denmark a divisor is used which compensates for the difference between Danish and English feet.

Some few years ago a method of measuring the holds of ships was proposed in France, but was not adopted by the French Government on account of the practical difficulties in the way of carrying it out. In measuring the transverse sectional areas, a starting point was to be taken just below the middle of the deck, and the two right angles being divided into an even number of parts, a radius vector was to be measured at each, the content of the transverse area being computed by an appropriate formula.* A fatal objection to this plan is that there are usually below the tonnage deck, flats and platforms, which would render the taking of diagonal measurements extremely difficult. On the whole, then, we think it may be said with confidence that the English rule of gross tonnage is a good one, sufficiently accurate without being unnecessarily precise, and based upon a principle of assessment which is as fair and equitable as can well be devised, when we consider the various kinds of ships which have to be dealt with, some carrying freights which pay by weight, some earning money in proportion to the space occupied, and others depending for remuneration upon the accommodation and comfort which they can offer to passengers.

The only rule of tonnage in force which will at all compare with the English system

* If the 180° be divided into n parts, then r_1, r_2, r_3, . . . etc. . . . r_n, r_n+1 being the radii,

$$\text{Area} = \frac{\pi}{6n}\left\{r_1^2 + r_{n+1}^2 + 4\left(r_2^2 + r_4^2 + \ldots \text{etc.} \ldots + r_n^2\right) + 2\left(r_3^2 + r_5^2 + \ldots \text{etc.} \ldots + r_{n-1}^2\right)\right\}$$

is that used by the Norwegian Government, to whom belongs the credit of having taken the first step in the application of correct principles to the measurement of shipping, their rule having been enacted in 1845, nine years before the English law. They divide the ship's length into four parts, whatever her size may be, and take but three breadths to each area, also leaving out of the consideration the round of beam. There are other minor differences, but in every case the English rule is on the side of accuracy. It is probable that in the case of wooden ships of moderate size, and of nearly uniform type, such as compose a large portion of the Norwegian mercantile marine, a small number of measurements would secure a true result, but whenever the question has been discussed by English naval architects the opinion has been pretty general that it would be dangerous to relax in any way the precision of our own rule, and that to make no deduction for round of beam would offer an inducement to builders to have flat decks, which would be highly objectionable for obvious reasons. Indeed, rough measurement did so much harm to our merchant navy in the past, by encouraging the design of abnormal forms for the purpose of evading tonnage, that we all have a wholesome dread of it now. In the American adaptation of the English tonnage rules a larger number of transverse areas is measured in each class of ship than in our own, the length being in the largest ships divided into fourteen parts; but of course their tonnage is taken to be sufficiently near our own to enable our Government to apply to them the reciprocity clause of the Act of 1862, our system of measurement being put forward not as the *maximum*, but as the *minimum* of exactness admissible. A few words will suffice to describe the imperfect tonnage rules of other maritime nations not yet particularized. Russia uses a rule almost the same as our old law of "builder's tonnage." In France, Portugal, Greece, and Italy, three dimensions only—length, breadth, and depth—are taken, and multiplied together and by a factor for the tonnage. By the Netherlands' rule, the length is divided into four parts, and at each point of division two breadths are taken, one being the greatest breadth of the transverse section, the other being taken at the upper side of the keelson. The mean of the six breadths is multiplied by the mean of the three depths, and by two-thirds of the length for the tonnage. In Spain three areas are measured, one at the foremast, one at the mizzen, and a third half way between them. Three breadths are taken at each transverse section, and the area obtained by using the well known trapezoidal formula. From the three areas, by the same rule, the cubic content is ascertained of the midship portion of the hold. The contents of the portions before the foremost area, and abaft the aftermost one, are obtained by multiplying the former by one half its distance from the stem, and the latter by one-half its distance from the stern post. In some of these rules deductions are allowed for provisions, water, pumps, etc., and in some cases the rules are subject to local modifications at the various ports. It will thus be seen that no other established system will stand comparison with our own so far as gross tonnage is concerned.

While the measurement of gross tonnage is so well provided for by the English law upon the subject, it is much to be regretted that the minor question of the allowance to steamers for propelling power is in a very unsettled and confused state. The principle upon which the allowance for machinery is made may be thus briefly stated:—In screw steamers, if the space actually occupied by the machinery be between 13 and 20 per cent. of the gross tonnage, the allowance is 32 per cent. of the gross tonnage. If, however, the machinery space is below 13 or above 20 per cent. of the gross tonnage, the allowance is $1\frac{3}{4}$ times the actual machinery space. In paddle steamers, if the machinery space is between 20 and 30 per cent. of the gross tonnage, the allowance is 37 per cent. of the gross tonnage; if below 20 or above 30, once and a half the machinery space. This rule was established by the Act of 1854, but its unfairness was so soon perceived that an effort was made in 1860 to alter it. A clause in the Act of 1864 authorized the Commissioners of Customs to regulate the details of measurement, and it was believed that it conferred power to make an alteration in the allowance. The question of the extent of the deduction to which steamers are fairly entitled has always been a debatable one, and the late Mr. Moorsom, the Surveyor General for Tonnage, in framing a new law, appears to have fallen back upon the principles which regulated the allowance under former rules. An act passed in 1819, the first relating to the measurement of

steamers, prescribes that from the length of the keel for tonnage (the rule known as "builder's tonnage" being then in force) the length of the engine room should be deducted, the remainder being esteemed the just length of the keel to find the tonnage; and in the law which succeeded "builder's tonnage" and preceded the present system of measurement, the allowance for engine-room was obtained by multiplying the length of the engine-room (between the bulkheads) by the depth amidships and that product by the inside breadth taken at two-fifths of the depth from the deck. Accordingly a rule was promulgated in 1860 by which the allowance for propelling power was directed to be thus estimated:—The length of the main engine and boiler rooms was to be measured between the bulkheads, a depth at the middle of the length, and the whole breadth of the ship at half this depth, the product of the length, breadth, and depth being taken with the addition of the shaft space, etc., for the allowance. The principle that the whole of the coal space, as well as the machinery space, should be deducted from the tonnage was not yet admitted, but it was considered that the side coal bunkers might be allowed, as it was not likely that the space occupied by them would be in any case used for cargo, both because of its contracted dimensions and its contiguity to the heated stoke-hole and engine-room. This rule was free from many of the drawbacks of that which it was intended to replace, but had this great fault, that it encouraged a particular form of engine-room, and, to a less extent, of midship section, and thus preserved the vice of the old laws, a legislative interference with the forms of ships. Vessels with long and narrow engine-rooms got more allowance than when the same space was occupied with less length, and as breadths of the ship were taken at half the depth, a ship with a rising floor had the same amount of tonnage deducted for a given length as one with a flat floor. Thus a ship with a peg-top midship section and a long narrow engine-room, with all her coals in side bunkers, got an allowance considerably in excess of the whole space occupied by the machinery and coals. Many steamers have their engines so fitted as to take up the whole breadth of the ship, and consequently would be placed at a great disadvantage by any rule of allowance depending merely upon length. A steam-packet company, which owned some ships fitted in this fashion, contested the right of the Government to set aside the rule of percentages, and the consequence was that in 1866 that rule was re-established and is still in force.

We have stated the terms of the percentage allowance, and to state them is all that is necessary to show their unfairness. In some steamers with large engine-rooms the legal deduction is nearly as much as the entire gross tonnage, but there is even a greater absurdity than this indicated by the fact that the owner of a screw steamer of, say, 4,000 gross tons, may sometimes, by the mere removal of a sleeping berth from the engine-room, be able to decrease his assessment to the extent of 370 tons. In 1871, a rule which appears to present a fair solution of the difficulty was inserted in the Merchant Shipping Code which was laid before the House of Commons, but which, as is well known, perished in the annual massacre at the close of the session. It is to be hoped that the exigencies of Parliamentary business will not prevent the Code passing into law during the present year, for many much-needed reforms are embodied in it, besides that which we are now discussing. The proposed rule proceeds on the principle of deducting the exact cubic content of the space occupied by the machinery and coals intended to be used in the propulsion of the ship; the total allowance to be limited to one-half of the gross tonnage, except in the case of tugs. To prevent coal space being exempted from tonnage when its contents are really cargo, it is directed that only those coal bunkers be allowed which have such provision for working the coals as clearly shows that the latter are to be used as fuel in the stoke-hole. Three transverse areas are to be measured in the engine-room, etc., and its cubic content otherwise accurately obtained. It is useless to enter into any lengthened argument as to the justice of allowing coal bunkers to be deducted from the tonnage; the present percentage system gives so large an allowance that the substitution for it of the most liberal rule which can, with any regard to consistency, be devised, will be a grievance to owners of steamships, and will provoke much opposition. It is usually understood that steamers have their machinery space exempted from assessment, because it is so much deduction from their carrying capacity, but it is difficult to perceive upon what grounds a greater allow-

ance can be claimed than the total space occupied by machinery and fuel, and yet the law as it stands at present gives them more. The evils of the present inequitable and, as a consequence, temporary rule have been conspicuously brought out in the course of the progress already made towards a system of international tonnage by the four nations who have accepted the English law of gross tonnage; no two estimate the allowance in the same manner, and this diversity is, except in the case of the American rule, which gives no allowance to steamers, distinctly traceable to the imperfect condition of the English law. Denmark adopted the rule of 1860 at first, but followed our Government when, in 1866, the percentage rule was re-established. Austria has adopted the principle of the allowance in the Merchant Shipping Code of 1871, but has decided to measure the engine-room by the rough rule of 1860—that is, by taking merely length, breadth, and depth, instead of transverse areas. The Imperial German Government has decided to use the exact rule of measurement of the proposed Merchant Shipping Code.

Besides the allowance for machinery and fuel, there is also a deduction made for the berthing of the crew, about which a few words appear necessary. At present, as much space as is fitted up for the crew is allowed to be deducted fron the tonnage, provided there is a certain minimum of space allotted to each man, and that some other conditions, favorable to the health of the crew, are complied with. This state of things was established by the Merchant Shipping Act of 1867, previous to which, space for crew had only been allowed when they were berthed above the upper deck, and then only to the extent of one-twentieth of the remaining gross tonnage of the ship. In the proposed Merchant Shipping Code the limitation is to be re-enacted, but the space will, as at present, be deducted, wherever situated. It certainly appears that, if the quarters of the crew are of such a character as to conduce to the health and comfort of the men, it is at least as reasonable to exempt them when below as when above the deck; and it is no less evident that, when there is no limit to the allowance, an opportunity for evading tonnage charges is offered to owners of ships which habitually carry heavy cargo, and the internal space in which is chiefly required for buoyancy.

The question of the allowance for steamers is certainly of much less importance in most other countries than in England, since they form a very small part of the mercantile marine of the Continent. They are, however, increasing in numbers every year, and it is daily becoming more desirable that this outstanding question of the deductions for machinery be settled, so that there may be an international register, as well as gross, tonnage. We venture to express a hope that the Government will not let the session of 1873 close without getting such laws passed as are necessary to perfect the English system of tonnage measurement, so that we may be able to offer it confidently, in its entirety, for the acceptance of other nations*.

* Since the above article was written the Transit Agents of the Suez Canal Company have published the following note: "Notwithstanding the recent decision of the Tribunal of Commerce at Paris in favor of the Messageries Maritimes Company, we beg to inform the Government and steamship owners, that the Suez Canal Company intend abiding by the terms of their Act of Concession, which gives them the right, as is shown by official documents published at that period, of levying a tax of 10 fr. per gross ton measurement. By adopting the English mode of measurement, and applying it to every ship passing through the Canal, they establish a uniform treatment for all flags, and thereby secure to the British shipowner immunity from those unfair advantages that steamers of other countries might derive by sailing with inaccurate papers."

CYLINDRICAL OR COLUMNAR FOUNDATIONS IN CONCRETE, BRICKWORK AND STONEWORK.*

From "Iron."

A description of an attempt made by the author, party in concert with Mr. J. W. Butler, A. I. C. E., to render concrete, brick, and stone, more easily available for cylindrical foundations. Brick cylinders have been in use in India for centuries, and have more than once been suggested for home works; but probably the engineers for the trustees of the Clyde navigation had been the first to adopt them in connection with a great and important undertaking. In 1869, Mr. J. F. Bateman, M. I. C. E., and Mr. J. Deas, M. I. C. E., had to report on the best means for providing a large and

* Institution of Civil Engineers.

progressive extension of quayage, suited to the present and future requirements of the harbor of Glasgow. With a view to obtain a greater depth of water than could be had alongside the existing quays, their attention was directed to iron cylinders, and subsequently to brick cylinders. The result was that, in 1870, an arrangement was made with the author, in conjunction with the late Mr. Brassey, A. I. C. E., to construct in brick cylinders to some extent, as an experimental work, the Plantation Quay, an extension westward of the wharves on the south side of the Clyde.

The Plantation Quay was founded on a hundred brick cylinders, sunk in a continuous line close together, so as to form a length of 400 yards of quay. The wells were 12 feet in external diameter, and 2 ft. 4 in. thick, thus having an internal diameter of 7 ft. 4 in. Their shape was circular, except at the points of contact, where they were formed with tongue and groove, *i. e.*, a square projection fitting into and sliding in a corresponding recess in the adjoining well. From the bottom of a trench, which was cut down nearly to the level of low water, the cylinders were sunk about 36 ft.; but the earth on the river side was removed when the sinking was completed, and dredged to a depth of 20 ft. below low-water level, thus leaving a length of about 14 ft. of cylinder beneath the dredged bed of the river. The cylinders were only carried up 2 ft. above low-water mark; a plug of concrete was then lowered to the bottom of each cylinder, to give it a proper bearing, and to protect the rest of the filling from disturbing influences, when the cylinders were refilled with the sand and other materials which had been excavated. On this foundation, suitably prepared, the rest of the quay was built as an ordinary retaining wall.

The shoe originally specified was that common in India—a flat annular plate with outer and inner shells, projecting downwards, meeting and enclosing a circular and wedged-shaped space. As this shoe was expensive, the author devised a shoe consisting of a short length of iron cylinder, about 4 ft. 6 in. deep, surmounted by an annular plate, which was also supported by radial brackets. The annular plate was about 18 in. in breadth; and the bottom courses of brickwork, which were bolted to the plate, were corbelled until the full breadth of the wall was attained. Instead of constructing the cylinders brick by brick, *in situ*, as was the custom in India, the author resolved, with a view to the expeditious execution of the work, to pursue the novel course of making them in rings, in frames placed on a platform near the line of the quay, and then to put them together, *in situ*, after they had been allowed to consolidate. Close to the line of the cylinders, over which was erected a high gauntry, with a steam traveller, a wooden platform was laid with a low gauntry, carrying a steam traveller. On this platform the rings were moulded in frames, which were constructed of wood in four sections, bolted together. Annular layers of wood were fixed to the platform, in such a way that their outer edges might keep the frames in place, while their inner edges served as guides in shaping the eye of the rings. When a ring had been built up with bricks and Portland cement and had partially set, the frame was removed, and the ring, which weighed between 9 and 10 tons, was allowed to stand a few days to consolidate thoroughly. When the ring had become thoroughly indurated, it could be removed by means of the travellers and a line of rails, either to be fixed in place or to be stored up for future use.

The sinking of a cylinder thus constructed was effected by means of the Milroy Excavator. The ground through which the cylinders were sunk consisted principally of sand, but the first three cylinders were impeded by old piles and tie-rods; about a dozen cylinders in the centre of the line encountered a bed of rotten sandstone, from 2 to 7 ft. thick, and a nest of boulders which were frequently met with throughout, had to be brought up in sinking the last ten cylinders. The whole of the one hundred cylinders were sunk between the months of August, 1870, and January, 1872; but from that period a large deduction should be made for those occasions on which the sinking was wholly or partially suspended.

The causes already referred to, and the unavoidable jamming of the cylinders, rendered very heavy weighting necessary. A load of 7 cwt. per superficial foot of frictional surface was required, and, to provide for this load, 900 tons of cast-iron weights were kept on the ground. The weights were circular, of the same diameter as the wells, 5 in. thick, and each weighed about 5 tons. A heavy load could thus be piled up in a small space, and at the same time there was no risk of the load tilting the cyl-

inder by unequal distribution, as was often the case when rails or pig iron were used. In sinking the last few feet the usual load was sixty-two iron rings, or 310 tons, which, with the weight of the shoe and brickwork (120 tons), made 430 tons as the load necessary to overcome friction.

Such was the system pursued in making and sinking the cylinders of the Plantation Quay. The use of frames in the manner described was found to secure straightness and uniformity of size, a reduction of the external friction by a smooth surface, and an avoidance of confusion in the line of the cylinders. The chief advantage was in the decided increase in the rate at which such a work as a quay wall could be executed.

In practical construction concrete differed from brick cylinders only in this, that they must be made in frames or moulds, and that an internal as well as an external frame must be used. In choosing between them the question was chiefly one of expense. When their relative cost was equal, concrete was perhaps to be preferred, as the process of mixing the concrete and filling the frame was so simple that it could be carried on, under proper surveillance, with unskilled labor. In this connection mention might be made of the application by Mr. J. W. Butler, of Mr. Ransome's artificial stone, on the same system as that employed by the author. Having conceived the idea that it was admirably adapted for the construction of cylinders, he made and sank, in 1871, at the Hermitage Wharf, on the Thames, some experimental cylinders with complete success. They were 8 ft. in diameter, and 9 in. thick. The courses or rings were moulded in frames, and were cemented together with the mixture of which they were composed.

From such illustrations it was evident that by the use of frames or moulds, not only might the old form of brick well be constructed more quickly and satisfactorily, and concrete and other materials be made available for cylindrical foundations, but every variety of form might be produced, suited to every variety of construction and of situation. Without pausing on the different modifications, the author drew attention to a further extension of the system, suggested by the difficulty experienced in sinking loose cylinders in lines or groups. The difficulty was to a great extent overcome: 1. By forming combinations of cylinders, incorporated with or moulded into each other, and sinking them together; and, 2. By so shaping them that a number of combinations could, if necessary, be tied into each other in a simple and efficient manner after they were sunk. The most satisfactory way in which a combination might be produced was by incorporating two, three, or more cylinders, so that their contours overlapped each other; and the combinations might be simply interlocked by producing at the points of contact a space or hole, which could be excavated and filled with concrete.

In conclusion, the author directed attention to the advantages which non-metallic cylinders possessed in comparison with iron. The principal one alluded to was that the first expense at present prices was much in their favor, with this important difference: an iron cylinder was, after all, nothing but a skin to which a weight-bearing body or lining must be given; whereas brick and concrete wells were themselves capable of sustaining considerable pressure. In short, iron cylinders, besides being dearer, must, when sunk, receive at least a lining, which it was evident could itself be sunk without the costly addition of the metallic skin.

THE ORDNANCE SURVEY OF GREAT BRITAIN.

From "The Architect."

THE SURVEY.

Let us now briefly sketch—it can be but a sketch—the various processes which are performed before the maps come into the hands of the public. We will suppose, for example, that an order has been given for the survey of Dorsetshire on the $\frac{1}{2500}$ scale, and that the secondary triangulation of that county has been finished. A party of observers, with seven-inch theodolites, is at once sent into the district which is to be first taken in hand, in order to prepare the minor triangles for the detail surveyors. For this purpose, the stations of the primary and secondary triangulations are used to fix a large number of intermediate stations, the positions of which are so chosen on the ground that they be well seen from one

another, and form well-shaped triangles with sides of something like a mile in length. Small whitewashed beacons or poles, doubtless familiar objects to many of our readers, are erected over all the stations, and the observations, as finished, are sent to Southamption, where the sides of the tertiary triangles are calculated to the nearest tenth of a foot; and where also the co-ordinates of the trigonometrical points are computed with reference to the sheet-marging, so that they may be afterwards laid down easily on the paper. Parties of "perambulators," or boundary-surveyors, are at the same time at work in the district, finding out the course of the public boundaries, and preparing outline sketches from which the chain-surveyor may be afterwards able to identify and fix the various boundary marks. A detail-survey "division" is now sent, let us suppose, to Dorchester, where its headquarters office is established; and parties of surveyors, each superintended by a non-commissioned officer of Engineers, are detached to towns and villages in the district about to be surveyed. Their first duty is to trace out and chain the sides of the minor triangles, noting in their field-books, as they go along, the positions of all fences, streams, and other objects which they cross, and leaving ground-marks or "pickets" at the points which may be most convenient for starting afterwards with the internal lines of the survey. The measured lengths of the sides of the triangles are now sent to the office, for comparison with the computed lengths, and when they are found sufficiently correct, the detail survey proceeds. This is done almost wholly by the method of right lines, one much more simple, and less liable to error, than that of "traverse-surveying," which is therefore only resorted to in emergencies, and in the highlands and uncultivated districts. By the right-line system, the surveyor simply chains a network of straight internal lines across and within his triangle, taking offsets right or left, as he goes along, to every object on the face of the country, and noting all measurements in his field-book. His skill and judgment are shown by his selection of these internal lines, which should be so directed that each may embrace in its course as many as possible of the features to be mapped, and that the survey of the triangle may thus be completed with the least possible number of lines. The quality as well as the quantity of the surveyors's work is subject to a very simple test in the office. The whole system of lines forms a sort of geometrical puzzle, and the plotter, having laid down the sides of the triangle on his paper, is at once able to find by actual measurement whether or not the internal lines will fit in their proper places, and can tell where any mistake has been made. When the chain-survey has been thus checked, and correctly finished, the contents of the field-book are plotted in pencil in the office, and a skeleton or outline drawing of the country is thus produced. This is now traced, in sections of a convenient size for further use in the field, and the tracings are placed in the hands of "examiners," whose duty it is to go over the ground, verifying the surveyors' and plotters' work, testing the boundaries, supplying the nomenclature, and the various characteristics, such as woods, parks, gardens, moors, antiquities, etc., inserting anything that may have been omitted, distinguishing the made roads from those which are unmade, and noting the state of cultivation of the fields, whether arable, pasture, waste land, and so forth.

With the completed tracings as a guide, draughtsmen in the office now transform the plotted pencil plans into finished drawings. The draughtsmen of the Ordnance Survey are justly renowned, and the 25 in. plans form admirable specimens of their skill; indeed, those done by the best workmen could hardly be excelled. All the plans are drawn on one uniform system, the same symbols, colors, types, and thickness of lines being adopted throughout the survey. Most of the work is done by hand, but woods, figures, and many of the names are stamped by lads on low rates of pay, and the more expensive labor of the skilled draughtsmen is thus economized.

CALCULATION OF AREAS.

The next process is to compute the areas of the enclosures as shown on the plans. This is done with the "computing scale," a beautiful and simple contrivance, invented by an *employé* of the department. By means of it the acreage of each enclosure is calculated separately; and as the sum of all the areas in each full sheet should be 960 acres, a ready check is thus furnished upon the accuracy of the computer's work. In consequence, however, of the daily expansion and contraction of the paper, absolute accuracy can seldom be attained, and

a small percentage of error, about two per cent., is allowed, and afterwards distributed. The acreages are calculated and made up separately for each parish, every enclosure having a reference number stamped upon it. An area-book of the parish is then compiled, in which the acreage (to the one thousandth of an acre) and state of cultivation of the several enclosures are entered opposite their respective reference numbers, and an abstract of the whole given at the end of the list; the area-book thus finished, is afterwards printed, and published with the plans.

As every landowner is primarily interested in the acreage of his property, it may be well at this point to explain the principle upon which the Ordnance Survey areas are computed. It must be obvious to the least experienced reader that, in a survey founded on a system of triangulation, none but horizontal measurements and horizontal areas can be given. To attempt to roll the country out flat—in other words, to take account of inclinations of the ground in the delineation of features or the calculation of areas—would be to defy all principles of accurate map making, and to pass beyond all limits by which the areas can be checked. The horizontal system, therefore, as the only one applicable to a general national map, is that which has been adopted for the Ordnance Survey. We believe, moreover, that it is the best and truest system. The produce of land, and therefore its real value for sale, or letting or taxation, are, if we mistake not, directly proportional to its horizontal area. Then, as regards tillage and labor on the land, it can hardly be doubted that both employers and employed would benefit in the long run by adopting as the final basis of agreement the areas given by the Ordnance maps. They would certainly gain in the prompt settlement of disputes, and in the saving of the sums now so constantly paid for land measurements to local surveyors. And although the laborer or ploughman who works by the acre naturally prefers to be paid according to the superficial rather than the horizontal measurement of sloping land, and doubtless thinks, if he ever thinks at all about the matter, that he is a considerable gainer by that mode of reckoning, the difference between the two is in reality extremely small, very much smaller indeed than is generally supposed, seldom exceeding two or three per cent. on the steepest slopes that can well be cultivated. For example, a square 10-acre field, on a slope of 1 in 4, measures nearly 9.7 acres on the horizontal plane, the two areas differing by no more than about three per cent. While on the subject of the acreage of estates, it is necessary to explain that private boundaries are not shown *as such* on the Ordnance plans; that is to say, no reference whatever is made to rights of property. This would need special machinery, and lead to difficult and protracted inquiries. All natural and artificial objects are, however, delineated; and as the boundaries of property nearly always follow the course of such objects, landowners are at once able to identify their own estates and holdings on the plans, and to ascertain their own acreage from the area-books.

LEVELLING.

To complete the plans, it now only remains to mark upon them the relative heights of their various parts. Every one has noticed the bench-marks cut upon many of the mile-stones, walls and gate-pillars along our chief highways in all parts of the country. They are the permanent marks of the Ordnance Survey system of spirit-levelling, a system which is so perfect and comprehensive as to merit a short digression for the purpose of explaining it. Just as the principal triangulation forms an accurate framework within which the minor triangles are afterwards laid out, in like manner, a series of lines of principal or "initial" levelling, extended over the kingdom, furnishes a definite basis for a system of interior lines of minor or "detail" levelling, which, as the survey proceeds, are carried along nearly every road in the country. The lines of the principal series, which were begun in 1839 and finished in 1861, were executed with great minuteness and care. They so often intersect and meet one another that numerous checks were thus afforded upon the accuracy of the work. Small discrepancies were of course absolutely unavoidable, and these were treated as a whole in each of the great series of levels for England and Wales and Scotland, and were rigorously worked out by the method of least squares, so as to make each series by itself perfectly correct and consistent. These reductions proved tasks of very great mathematical difficulty; that, for example, of the English series ultimately involved the solution of a system of equations with ninety-one unknown quantities.

In connection with the trunk lines of levelling, tidal observations were made at a number of stations round the coasts of Great Britain, for the purpose of finding the relative heights of the *mean tide levels* at all the stations, that is to say, of the levels corresponding to the mean or average height of the sea at each station, as derived from long series of observations made at small equidistant intervals at all times of the tide. These mean tide levels were found to differ considerably at the various stations, the extreme difference amounting to more than thirty inches. An average of the whole was then taken as the *mean level of the sea* for Great Britain. It was now necessary to adopt some fixed datum-level, to which the whole system of Ordnance Survey heights might be referred. For this, the mean tide level at Liverpool, which, according to the most trustworthy determination, is 7.47 in. lower than the mean level of the sea above referred to, was chosen. Every altitude marked upon the plans, from Cape Wrath to the Land's End, is accordingly expressed with reference to this one Liverpool datum, and is therefore strictly correct in its relation to every other altitude, no matter how far apart the points may be. In a similar manner, a mean level of the sea has been found for Ireland; but, as this was not done till after the engraving of the sheets, the levels on the Irish maps are all given with reference to a datum previously fixed upon, viz., low water at spring tides at Poolbeg Lighthouse, in Dublin Bay, which is 8.094 ft. below the mean level of the sea round the coast of Ireland, as since determined.

The detail levelling is carried out, as we have already intimated, contemporaneously with the progress of the cadastral survey. Starting from marks on the initial series, lines are run along nearly all the turnpike and parish roads, and bench-marks cut at intervals of about a quarter of a mile. The whole of the bench-marks of the initial and detail levelling are shown in position on the 25-in. manuscript plans, and their heights given to the nearest tenth of a foot. Surface-heights, to the nearest foot, are also marked on the plans, at frequent intervals between the bench-marks. In towns, surveyed on the $\frac{1}{500}$, or the 5-ft. scale, the lines of level are carried along every street, and bench-marks and surface-heights are much more frequently given.

The manuscript 25-in. plans of our district are now finished, with every object shown in its true position and character, the names correctly given, the trigonometrical points marked, the public boundaries defined, levels scattered over the surface, and the plots all numbered in correspondence with the parish area-books. Thus complete, they are finally examined on the ground by the officer in charge, and then forwarded to Southampton for publication.

TOWN SURVEYS.

In the survey and mapping of towns on the larger scales, the processes followed are in all respects on the same principle as those which we have described for the rural lands, though of course more minute and tedious. A number of extra trigonometrical points within the towns are fixed from surrounding stations, but, from the nature of the work, it is generally necessary to make the surveys in blocks or multagonal figures, rather than in triangles. The levels, as we have remarked, are much more numerous in towns than in country work. No attempt, however, is made to compute the acreages of the innumerable plots, and the area of each town as a whole is alone given.

REPRODUCTIONS OF THE PLANS.

The parish and town plans, after having been once more thoroughly examined at Southampton, are published by zincography, a process which was adopted on the Ordnance Survey in 1855, and which, though closely resembling lithography, is yet in several respects superior to it. The work turned out is equally good by either process; but while a lithographic stone of the area necessary for the Ordnance plans is about 4½ in. thick, costs about £7 and weighs 450 lbs., thus requiring four men to lift it, a zinc plate of equal surface is but $\frac{3}{16}$ of an inch thick, cost only £16, and weigh no more than 60 lbs., so that it can be easily carried by one man. The zinc plates also wear extremely well, and are less liable to fracture than the lithographic stones. Those used on the survey are of the best Silesian zinc, and the surface is prepared by successively scraping with a razor-blade, grinding with pumice-stone and water, smoothing with steatite or "water of Ayr stone," and graining with moulding-sand. The outline of the manuscript plan is traced in lithographic ink, on tracing-paper thinly coated with starch or paste. This, for the sake of cheapness, is done by

boys, but the writing and characters are added by a superior workman; boys also stamp the woods, figures, etc. The remaining processes of transferring the tracing to the zinc, and printing the impressions, are exactly the same as in lithography, except that a different "etching liquid" is used for the zinc. Each parish on the $\frac{1}{2500}$ scale, and each town on the $\frac{1}{500}$ or the 5-ft. scale, is published separately, as soon as ready. For the first edition, it is usual to take from thirty to a hundred impressions of the plans, according to the probable demand. After this, the zinc plates are cleaned off, and re-prepared for other sheets. It is found to be cheaper and more convenient to do this, and to make fresh tracings from the manuscript plans when a second edition is wanted, than to keep the plates idle meanwhile. A transfer on zinc will, however, print more than 1,000 copies if required, without sensible deterioration. The printed sheets, after having been dried and pressed, are passed on to boys, who color the houses, roads, and water. The edition is now ready for sale. The publication of the zincographed plans, at Southampton, is under the excellent immediate superintendence of Major R. M. Parsons, R. E., who also has charge of the photographic and photo-zincographic branches.

At present the staff on the survey consists of about 1,925 persons, including twenty officers and four companies of Royal Engineers, 900 civilian assistants, and 500 laborers and chainmen.

CIRCULATION IN BOILERS.

From "The Engineer."

Circulation in boilers may be defined as a continuous change of place in the water within them. It means the existence of a continuous flow of water over the heating surfaces, and it is essential to the success of all boilers, except perhaps those using distilled or other very pure water. It is commonly taken for granted that under no circumstances can a rapid change of place in the masses of water within a boiler be dispensed with; but we think there is reason to dispute the accuracy of this conclusion. If, for example, we take a tube 5 or 6 in. in diameter, and a couple of feet long, fill it with distilled water and apply heat, it is clear that we can cause continuous evaporation witont doing any harm so long as we keep the tube supplied with water. It is not necessary that a constant current should flow through the tube; internal circulation will take place with sufficient energy to keep the surfaces supplied with water as fast as the steam drives it away. However, when water holding lime or other compounds in solution is used, unless a current is established through the tube sufficiently strong to sweep away the deposit as fast as it is thrown down, there is danger that the surfaces will become furred up, and that the tube will be overheated and destroyed. The more impure the water the greater is the necessity for good circulation. The purer the water the more moderate may be the rate of flow over the heated metal. Thus, in the high pressure tubular boilers used by Mr. Perkins, the rate of circulation is extremely moderate, and there is good reason to believe that the small tubes, when the boiler is making steam, never contain really "solid" water at all. But no evil consequence whatever ensues, because the water used is invariably distilled, and therefore perfectly pure and free from lime or mud. We have spoken of tubular boilers, but it is obvious that what we have said applies to all boilers of whatever kind, whether Cornish, locomotive, or cylindrical. In the last three types circulation is left to take care of itself, and the action of such steam generators is so well known that we need not say much about circulation within them. The water tube, or tubulous boiler, is, however, rapidly growing in favor, and from the nature of the case special arrangements must be used in such generators to secure circulation, that is to say, the passage of a current of water ower the heating surface, when water not distilled is used in them; and as a good deal of misapprehension exists on the subject, it is worth while to call attention to one or two facts usually overlooked.

We find that in a large proportion of tubulous boilers circulation is obtained by heating one leg of an inverted siphon more than the other leg. The steam and water rise in the hotter leg and the water descends in the cooler leg, and so circulation is maintained. The siphon assumes various modi-

fications. Thus when a vertical tube with an internal circulating tube is employed, the inner tube constitutes the cool leg, and the outside tube the hot leg of the siphon. In other cases the water descends in the annular space round the outside of the fire-box, which space constitutes the cool leg, while the steam and water rise through tubes within the fire-box, these tubes constituting the hot leg. The popular faith is that the mixture of steam and water in the hot leg weighing less than the "solid" water in the cool leg, is over-balanced by the latter, and that circulation is the result. We believe that this theory is only in part true, and it may follow that a boiler in which the circulation is apparently most violent, may not only be a less economical generator than one with very moderate apparent circulation, but more likely to be burned out. In fact, considerable advantages may in certain cases be obtained by restraining circulation instead of facilitating it. If we suppose the case of a tube bent to the shape of a U, one leg of which is filled with steam and water while the other is filled with water alone, it will be found that the pressure at the section dividing the mixture from the "solid" water is just the same as though the tube were quite full of "solid" water. The steam bubbles rise simply for the same reason that a cork sunk to the bottom of a bucket of water will, when released, fly to the surface. It is about as reasonable to suppose that a current will flow from the cold leg to the hot leg because the last contains bubbles of steam, as it would be to suppose a current would ensue if, cold water only being in the tube, we put a number of corks into one leg. The presence of the bubbles of steam can in no way affect the hydrostatic pressure in the tube; and unless there is a difference in the hydrostatic pressure of the two columns of water there will be no current.

It is certain, however, that under the conditions we have cited there is a current, oftentimes to all appearance very violent indeed; but we must not judge by appearances in this matter, and cases have come under our own observation in which tubes were burned, although it appeared that water was rushing through them. Nothing is easier than to confound an upward rush of steam, mixed with a very little water, with an upward rush of boiling water; and many boilers for which it is claimed that the circulation is perfect, really have little or no true circulation. The great agent in securing the motion of the water is not the assumed fact that a column of mixed steam and water is lighter—that is to say, exerts less hydraulic pressure—than a column of "solid" water of the same depth; it is the fact that the water in one leg is hotter, and therefore lighter, than it is in the other leg; and in a well-designed and proportioned water-tube boiler, very active circulation goes on from this cause, not only when steam is up, but almost from the moment that the fire is lighted. This is the principle which should be rendered available in the design of water-tube boilers. No dependence whatever, indeed, is to be placed on boilers in which there is practically no circulation until steam is up. It would be invidious to mention names, but we may state that we refer now particularly to one or two types of sectional boiler recently brought out in the United States, of which great things are promised, although, as we think, there is not the slightest ground for forming favorable anticipations of the success of these generators. To the same category may be referred many devices patented by both American and British inventors for effecting forced circulation—as, for example, when a coil of tubes is placed in a furnace, and the water is driven through the tubes by a pump worked by a steam engine, or by a screw propeller, or a turbine, or a modification of the injector. Many such schemes have been tried, but we cannot call to mind a single instance in which a boiler obtained any success or permanent popularity unless it was so constructed that circulation began the moment heat was applied to the water and continued without any extraneous aid. And yet, with all this, there is apparently much to commend the forced circulation theory. In practice, however, the extra cost and complication, and the possible destruction of the boiler should the circulating apparatus fail, even for a few minutes, has told heavily against it, while the *coup de grace* has been given to such schemes, by the fact that sufficient circulation can always be obtained in a properly designed boiler without adventitious aid.

In considering the whole question of circulation in water tube boilers, two facts must be borne in mind; the first is that the circulation does not require to be very violent, provided the volume of water passed

over the surface bears a fair proportion to the volume of steam generated. Thus, for example, we may have two tubes, one of which is filled with froth passing through the tube at a high velocity, while the other tube is filled with boiling water moving at a comparatively slow speed. In the second case the circulation is obviously more efficient than in the first, and it is advisable when a tendency to the production of froth exists, to reduce the rapidity of the rising current, and so compel the presence of more or less solid water in the tube. This principle has been very perfectly applied in the Paxman boiler. We may put on one side, however, all vertical boilers, and confine our attention solely to the sectional boilers, often of very great power, now being produced by the dozen in the United States, and go on to point out that the second point to be borne in mind is that we are much less likely to have a hard and dangerous deposit from a considerable body of water moving slowly, than we are from a rapid but shallow current. When a tube is pretty well full of water, the agitation or ebullition going on is likely to keep the particles of lime suspended until the water has got out of the tube to some quieter place; when, however, the tube is small, and the production of steam so rapid that much water cannot remain in the tube, although that water flows rapidly, it will leave deposit behind it. As there is nothing like the logic of facts, we may point out that a most efficient "separator" and heater—Stillwell's—depends for its success solely on the fact that a thin stream of heated water flowing over a succession of sheet-iron trays will throw down nearly all the sulphate of lime which it contains. The deposit forms on the trays, notwithstanding the current, instead of on the heating surface, and the trays can be taken away and cleaned, or, as they are very inexpensive, replaced with new ones without trouble. If the water passed over these trays in a considerable body the suspended impurities would not be got rid of so effectually. It appears, then, that in practice it is advisable to use comparatively large tubes, with a moderate rate of current, rather than small tubes, in which, although there is apparently a very rapid current of water, there is in reality very little else than steam.

The means of producing circulation are extremely simple. That most ordinarily employed consists in inclining the tubes so that one end shall be higher than the other. Some inventors lead the water into the lower end of each tube by a down pipe placed in a cool place, the steam and water running along the inclined pipe, and this is beyond question a very excellent arrangement. Others employ an internal circulating pipe, which carries the water to the lower end of the generating tube. This does not appear to work unexceptionably well; at all events, Messrs. Howard, of Bedford, have abandoned the use of the internal tube. They state that they find that water enough for all practical purposes makes its way down the tube from the top, if a deflecting plate is fitted across the mouth of the tube at the upper end to turn the escaping steam away from the entering water. As the tubes are of considerable diameter, and quite accessible for cleaning, little circulation is required except that necessary to prevent the tubes from boiling dry. Other makers use horizontal tubes, united by short lengths of vertical pipe. One set of these vertical pipes must be kept cooler than the other set, or there will be no circulation. The water rises in the hot pipe, and forces its way, so to speak, into the tube, driving the water before it to the other end, where it descends down a cool pipe, or else ascends through a second short length of circulating pipe to a generating tube above. The action is just the same as though the tube were laid on an incline.

The lesson we have endeavored to convey is, that little or no dependence is to be placed on steam as a means of securing circulation; that ought to be got by establishing communication between two columns of water, one hotter, and therefore lighter, than the other. It must not be forgotten, however, that although steam can not act as a circulator by reducing the hydrostatic pressure of a column of water with which it may be mixed, it does act under favorable conditions to change the water in another way, which is this: when a bubble of steam is formed in the ascending leg of a siphon or its equivalent, it displaces a volume of water equal to its own bulk, and if there is sufficient inducement the displacement will take upwards. The water will escape then from the upper end of the siphon, and the deficiency will be made up when the steam has gone, by water from below. Steam will also carry water up with it in rising; but this is objectionable rather

than the reverse, because the steam with its load of water cannot rise upwards without exerting a corresponding reaction downwards, and so tending to prevent the entrance of water from below. The utmost possible care should in all cases be taken to keep the descending circulating pipes of a boiler cool. Cases have arisen in which boilers, otherwise good, have utterly failed from neglect of this precaution. In a U tube hanging from the roof of a fire-box, and with both legs equally hot and of the same length, there will be no circulation whatever; the tube will boil dry and burn out. But if one leg be protected from the action of the fire a steady circulation will ensue. Inventors, desirous to get all the heating surface they can, have now and then overlooked this point to their own discomfiture.

On one more point it is necessary to say a word: care should be taken to secure a diffused, not a local circulation. It is not difficult so to manage matters that the entire circulation may be confined to ten or a dozen tubes out of twenty or thirty. The others are then liable to be deprived of water and burned out.

THE ARCHITECTURE OF MUSIC HALLS.*

From "The Builder."

Music is pre-eminently a modern art—the only form of high art which had its rise during the era of modern life, and therefore there cannot be a precedent available of a building adapted for performances on a scale like those with which we are every year becoming more familiar. To supply buildings which shall give the highest effect to these grand artistic entertainments, which shall place performers and audience in the best relative positions, is a responsibility which has devolved upon the modern architect. A great deal has been already said (notably by Mr. Roger Smith) upon the formation, conduction, and reflection of sound, and upon the relative qualities of materials; but it semed to the author that the subject had hitherto hardly been regarded from what might be called a musical point of view, and therefore he proposed to offer a few suggestions based on some acquaintance with musical art, as well as with performances of many kinds.

We may either employ (1) materials, such as woollen stuffs, curtains, and draperies, which will damp all resonance and absorb all sound as soon as it strikes the sides of the room; or (2) we may seek for materials which will give a direct and sharp reflection of the sounds that infringe upon them, as stone, marble, polished cement or plaster; or (3), we may select materials which will neither sharply reflect nor absorb the sound, but will, if one may use the expression, sympathize with it, adopt its vibrations, and strengthen and intensify its tone, without reflecting it back in such a manner as to cause confusion or annoyance to the ear. There may be circumstances in which the first system has its advantages; the Liverpool Philharmonic Hall is full of curtains and upholstery, and what is heard there is heard distinctly and without disturbing influences; but it is a very dead room, very deficient in sonority, and the effect of the band is impaired by this. The only case, perhaps, in which such a muffling of a room might be of service would be that of a very large hall intended mainly for organ performances; for the organ requires scarcely any assistance from the room, while, on the other hand, its effect is more readily confused and impaired by reverberation than that of any other instrument. The second system, that of employing sharply-reflecting substances, cannot, under any circumstances, be otherwise than positively injurious to musical effect. In a small room it imparts a meanness and hardness to the *timbre* of the music; in a large room it produces, of course, echoes which go far to do away with music altogether. This may be observed in our cathedrals, where the organ music especially becomes, when at all loud, a maze of indistinguishable sounds rolling about the building. Although this is popularly supposed to be very fine, yet effects of echo are not "music," but only a disturbance of music. The third system is that of employing resonant but not highly reflective materials; and of these by far the best, and perhaps for practical purposes the only one available, is wood, which has been

*Abstract of a paper read before the Royal Institute of British Architects by Mr. H. H. Statham, Jr.

adopted in the Albert Hall. The result, considering the size of the room, has been a decided success; and the degree of clearness with which a single voice can be heard there is to be attributed, in great measure, to the resonant wood lining. St. George's (Liverpool) Hall, on the other hand, is an example of a room constructed entirely of reflecting materials - marble, stone, tiles, and cement, and is a most trying room for a solo voice, insomuch that vocalists have failed to satisfy an audience in this hall, and have been most unfairly judged in consequence. But the contrast is most marked in regard to the organ; and here the opportunity for comparison is unusually good. St. George's Hall contains the only other organ in England of the same size as the Albert Hall organ, built by the same builder, and played upon mostly by the same player. Now, in St. George's Hall, the effect of loud organ music, of an intricate description, is an absolute chaos; while in the Albert Hall, though the resonance is in excess, it does not materially interfere with the effect of the music. Curiously enough, the organ builder had recommended that the floor of the Albert Hall should be laid with tiles and the walls finished in polished plaster; but, fortunately for the organ, this advice was not acted upon.

Coming now to the arrangement and planning of concert-rooms, we find this matter has received in general comparatively little attention, if we may judge from the results. Most of our concert-rooms are a kind of enlargement of the old ball-room model, with a flat floor for dancing and promenading, and an orchestra for the players, out of the way; and this plan is mostly adhered to, although we have long ago recognized in our theatres the necessity of placing the auditorium at such a slope and angle that all may see and hear what passes on the stage. The Albert Hall is in its general design as much the result of precedent as any other music-room, and it is exactly in proportion as it is so that it is not successful as a music-hall. It is based avowedly on the form of the Roman amphitheatre, as our other music-halls are (unavowedly) upon the English ball-room. The building is really one in which an audience occupying a part of the hall are to hear music performed by an orchestra at one end of it. The conditions for the favorable placing of those who are to produce, and those who are to hear the music, are so different, that on the usual theoretic principles of architectural design, such a disposition would certainly appear to involve a totally distinct treatment of the two extremities of a building. The arrangement of the seats brings a considerable portion of the audience into an altogether wrong position for hearing; that everybody can hear is true; the question is, what do they hear, and is it what they want to hear? Now the orchestra and a large part of the auditorium form part of the same ellipse, only separated from each other by an arbitrary division so placed as to mark off space for a sufficient number of performers; indeed, on the seats adjoining the orchestra the audience are seated nearly behind the singers, at all events behind the direction in which the sound is impelled; and are hearing one side of the chorus close to them, while the other side is in the distance, at the opposite extremity of the orchestra. This is the inevitable result of applying to a building for music an arrangement originally intended for a spectacle. If it were decided that the amphitheatre form of building was to be adopted, the best arrangement of the auditorium for enabling an audience to hear an oratorio satisfactorily would probably be where they are all brought in front of and facing the performers, and the disadvantage of a position at one side of a large orchestra is reduced to a minimum.

But it is probable that for the execution of great works of combined choral and instrumental effect, neither the amphitheatrical nor the theatrical form will be found the most suitable. The amphitheatre, though its symmetry and simplicity may seem to recommend it, has this serious disadvantage (when used on a large scale), that the sound, as produced in the orchestra, is not properly controlled and confined in the direction in which it is most wanted. A certain proportion must be observed between height and width, and the wide area of an elliptic amphitheatre requires a lofty roof, and consequently a great space for the production of echo. Something approaching to the theatre form is better, as the orchestra can then be confined under a lower roof and between side walls, and the sound driven forward more. On the whole, it will probably be found that the requirements of the case are best met, and the difficulties best avoided, by the long form of room, rather than

the theatre or amphitheatre form, and that construction is a more direct and successful way of conveying the sound to the audience than radiation. The waste space of air in a room of this size may be made much less in proportion to the area than in an amphitheatre. For the successful conduction of sound through a long building, it is essential that it should be confined from spreading above or at one side of the performers, and reflected forward as strongly as possible; that the height of the auditorium, though greater than that of the orchestra, should not be such as to give room for any unnecessary loss or dispersion of sound, or to allow space for a disturbing echo from the roof; that for the same end the roof should be nearly flat rather than circular, so as not to collect and focus any reflection of sound which may be inevitable. The orchestra should be constructed principally of wood, and the walls of the auditorium lined with wood; but the walls, as well as the ceiling, require to have their otherwise flat surfaces broken at intervals by projections, in order to avoid the conduction of sound along the walls, and break up any reflection from the ceiling; and careful provision must be made against a return echo from the end of the room. As to arrangement of the audience and performers in regard to one another, one of the principal advantages of the longitudinal room is that the audience all sit facing the performers; not only a better position for hearing, but more confortable in every way; for although we do not hear with our eyes, there is an irresistible tendency to look towards the quarter from which the sound comes; and in a side gallery in a music-hall the audience will be seen with their heads all turned sideways to look at the orchestra. A room with a flat floor, however, is always unsatisfactory for hearing, and the seats should always rise as they recede from the orchestra. Another point to be considered in placing the audience is, that for a performance on a large scale, no person who wishes to enjoy the music, or to realize its true effect, would ever choose to sit close up to the orchestra. As concert-rooms are generally arranged, it may be taken as a rule that for this class of performance all the first ten or twelve rows of seats, if not more, are thrown away, so far as any real enjoyment of the music goes. Now, we generally find, in connection with concert-rooms, a considerable space in front of the audience end occupied by a large lobby or crush-room, serving mainly as a waiting-place for relieving the pressure of the crowd in going out or coming in. The author proposed carrying the auditorium to the very back of the building, and making the entrances to the principal portion of it at the sides, transforming the space usually occupied by the front seats, into a vacant space which may act as a crush-room or *foyer* before and after the concert, and as a promenade during the interval. If this space were laid with parquetry flooring on joists, with a hollow space underneath, it would not only make a very effective entrance to a room, but would probably act as a reflector and reinforcer of the sound from the orchestra. It may be observed that there should never be a centre aisle between the seats in a concert-room, as this places the solo singer opposite an empty strip of floor instead of a range of appreciative countenances. The possibility of draughts to the performers appears a more serious objection to this placing of the entrance, but this may be obviated by making the lobbies to the cloak-rooms the approach to the inner lobby, and having no direct communication between it and the outer vestibule; and by keeping the inner lobby well warmed and with a sufficient outlet at the top, any draughts which might be drawn in would be disposed of here, without finding their way into the concert-room.

In regard to the orchestra: it may be said that the placing of the various performers not only so as to be well heard by the audience, but so as not to incommode each other, has been almost entirely overlooked in most cases. It is generally considered sufficient to make a tier of semicircular stages, one behind another, and the band and chorus fit themselves into these, while the solo singers find room where they can in the narrow strip left for them in front of the band. The band is immediately backed, not by any sound-reflecting substance, but by the mass of the chorus, whose dress forms a body of sound-absorbing material; and, on the other hand, the singers are liable to be put out and disturbed by the noise of particular instruments close to them; for it may be supposed that a chorus singer is not likely to go through his part the more correctly with a trombone bellowing in his ear something quite different from what he is singing. The construction of the orchestra which the author proposed

as an improvement is, to enclose the band with a kind of wooden shell or sound-board bending round them in the rear, and coming under their feet to the front, the stages on which they stand being carried by framing at intervals. The sound board would be carried above the heads of the upper rank of the band and bent forward over them to some extent; and then above and behind, this and on the upper level, would be ranged the chorus seats. By this means it was expected that the sound of the band would be thrown forward into the room, while at the same time the sound, especially of the brass instruments and drums (which are always at the back), would be to a certain extent veiled from the singers, who would be able to hear their own voices better, and hear the band as a consecutaneous union of instruments, instead of having here and there a particular instrument close to their ears, drowning everything else.

The author exhibited a plan of an orchestra arranged for a band of about eighty, the performers being placed in the relative positions at present adopted. If the stages are made about three feet wide it will be found sufficient for the violins; the two back rows should be wider to allow plenty of room for the larger stringed instruments. About three feet longitudinally should be allowed for each violin, and about a foot more for the violoncellos; the basses, which are very bulky instruments, must be reckoned as requiring 5 ft. to each player. A platform the width of two stages should be left in the centre of the two top rows for the drums, which, for want of such provision, are often very inconveniently placed. The wind-instrument players require little more than easy standing-room longitudinally, their instruments not necessitating much action in playing. The organ should be at the back of the whole, behind the chorus, to whom it is the greatest assistance, and it should, wherever possible, be rather spread out laterally behind the singers than projecting forward among them in a square mass; the latter is bad, as it places a part of the chorus on each side, in a recess where they are not well heard and cannot hear each other. The rest of the space behind the singers would be filled up by a wooden partition like that behind the band, or it may be partially filled by carrying round some of the larger organ pipes in a segment of a circle, which would add very much to the architectural effect. The organist should *always* be placed below in front of the whole orchestra, which, now that the electric movement can be applied, is easily done. Lastly, the solo singers should be advanced on a small projecting platform of their own, so as to be a little nearer the audience and further from the band; by this means not only will their voices stand out better, but they will not be incommoded by the too near proximity of the band.

Very large ideas have been afloat lately as to the number of persons who may be accommodated to hear music in one building; and a well-known writer on architecture has made it a charge against us that we are content with getting three or four thousand people into a concert-room, whereas, if the buildings were properly arranged, four or five times that number might hear. This idea would be found to be a complete fallacy, and one which those who build such rooms should discourage. It is impossible by any acoustic expedients to secure that music should be intelligibly heard and effectively rendered in rooms beyond certain limits of size.; 15,000 or 20,000 people may be grouped in such a way that they shall all be within sound of the performers, and have a general notion of what is going on, but that is not hearing music. It does not in the least follow that because 500 performers produce a certain effect in a building of a certain size, that 2,000 will produce an equal effect in a building of four times the area, and for two reasons. The organ can be in some degree adapted to an increased scale of building, because its sounds are produced purely by mechanism, and by a heavier pressure of wind they can be forced up to a proportionate strength, although these huge over-blown music-mills do not give as much pleasure to the ear as the old quieter instruments. But in regard to other instruments and voices, increase of power can only be got by multiplying the numbers, and this is not the same thing at all. With increase of numbers comes decrease of delicacy, accuracy, and precision; and besides, a peculiar indistinctness and want of sharpness of effect, better felt than described, as if the outlines of the composition were blurred and uncertain. In the second place 15,000 to 20,000 people cannot be accommodated within hearing of music at all except in a building having a great cubical capacity in proportion to its area; that is to say, a vast

mass of air space between the performers and a great portion of the audience, and sound cannot, by ordinary means, be forced through this space without a liability to be dispersed and disturbed in its passage.

You do not hear particular instruments come in when they ought, but you find them out when they have got half through a phrase. This singular effect is found commonly in the Albert Hall, and the corollary from all this is, that great buildings like the Albert Hall are unsuitable for a clear and intelligible rendering of music; and the result would have been far more satisfactory, for this end, if two halls of half the size had been built, and the audience and performers divided between them. It may be possible to enable 10,000 people, or at all events 8,000, to hear 500 performers satisfactorily, but I do not believe it is possible to enable 20,000 to hear 1,000 with the like result.

In comparing vocal and instrumental concerts, it must be remembered that voices can be satisfactorily heard in front only, but the greater proportion of instruments can be heard nearly equally well all round; even the wind instruments, which come nearest to the conditions of voices, can be heard as well sideways as frontways for all practical purposes, and can be very fairly heard even when playing away from the listener. For this reason a central position may become the best for the performers in a building intended specially for chamber music, which is mostly set for three, four, or five-stringed instruments. It is absurd to suppose that the same concert-rooms which are suitable for an oratorio performance can be suitable for this fine and delicate class of music. To treat chamber music so is as reasonable as it would be to place a statuette intended for a drawing-room in the centre of a large square. What is wanted in this case is a room where all the audience shall be as near as possible to the performers, and where there should be as little waste air space as possible, and therefore the centre of the room is quite the most suitable place for the performers; and a circular building, with concentric ranges of seats, and a raised platform in the centre, would be probably the best form that could be employed. It was not known till the other day that this idea had been practically adopted for some time past at M. Pasdeloup's Sunday instrumental concerts in Paris, which are given in a building at other times used as a circus, the orchestra being placed in the centre.

There is one instrument which is the means of bringing architecture and music into more direct and immediate relation than any other. The organ, which really is not so much an instrument as a second orchestra in itself, not only demands great practical care as to its position and surroundings, but forms in itself so important and permanent a feature in a building—an edifice within an edifice—that its design and architectural treatment become a matter of some moment. The architects of the Classic revival, from Wren to Elmes, seem to have had a special spite against the organ, and to have regarded it generally as a nuisance interfering with their architectural compositions. The architects of the Gothic revival profess often a great interest in the organ, but the unfortunate instrument, or its representative the organist, might well exclaim, "Save me from my friends." The greatest ingenuity could devise nothing more ruinous to the effect of the instrument than the "organ chambers" in which it has become the almost universal practice to confine the instrument; placed under a low roof, and its sound only allowed to escape through arches on two sides (and sometimes only on one side), all possibility of anything like grandeur of effect is removed, and the result is, a great noise in the immediate vicinity of the instrument, and a muffled and unsatisfactory effect further off. The position is bad in other ways, for it is commonly against two outside walls, subjecting the instrument to changes of temperature, and cramping it up into too small a space, which not only increases the chances of disarrangement of the mechanism, but the difficulty also of keeping it in repair. There ought to be room for all the pipes without crowding, and for every part of the instrument to be got at without disturbing any other part. This is scarcely ever the case in the conventional organ chambers. If, from ritual considerations, the choir are to be at the east end, the organ must be near them, but need not be in a cage; it should be provided for in an open transept near the choir, and the same height as the rest of the church, or nearly so. If, from any circumstances, the architect is compelled by pressure from without to adhere to the organ chamber, the floor of this should be made lower than that of the church (proper

provision being made against damp); the bellows and other parts of the mechanism will then go below the floor, and the pipes may have a chance of being sufficiently low to sound fairly through the arches. But, taking the question on musical grounds alone, there can be no doubt whatever that the west end of a church is the place for the organ, even if it has to be placed in a gallery in order to clear a west doorway, though it is of course better nearer the floor, and merely on a raised platform. In cathedrals by far the finest position for the organ, in regard to effect, is the time-honored place on the choir screen. In almost all our concert-rooms the organ looks like an after-thought, put there with no relation to the general design of the room. In St. James's Hall the organ is balanced on the top of some long posts. In the Albert Hall the organ is a monstrous excrescence, and the case, if case it can be called, has positively no relation whatever in point of design, either to its position or to anything else in the building. So it is, more or less, in most instances. This might be avoided. It is generally possible to ascertain at the outset, when a large concert hall is being built, the intended size and position of the organ; and this should be made a portion of the design from the first, the basis, at all events, on which the organ stands being connected with the architecture of the room, in a permanent manner.

The decorations of concert-rooms seem to range under two heads—*cupids* and *pilasters*. In different essays, and suggestions, we are told that the wall must be "broken up with pilasters" at certain points, to prevent echo, etc., and instances are given in which the breaking up has been successfully accomplished in existing buildings. If it is desirable that the wall-surface should be broken up, what, in the sense of genuine architectural treatment, does that mean? Simply that the curtain walls between the main piers or buttresses are to be set back from the interior face of the former. If the interior is best lined with wood, need we make it like a huge painted bandbox inside, with applied (so-called) architectural features? Rather, may we not use the wood visibly and confessedly as a lining between the points of support, making the most of its natural texture and tint, contrasting various woods, making use of parquetry or surface carving where means will allow? So on through every acoustic and musical requirement of a building; there is surely no reason why such things should be architectural shams, any more than anything else.

Mr. T. Roger Smith proposed a vote of thanks to Mr. Statham for his exceedingly valuable Paper, and said it was a very useful thing to hear Papers read on subjects by gentlemen who possessed special qualifications for dealing with them. With regard to the capabilities of halls for accommodating large audiences, he might say that a very surprising effect was produced in performances on a large scale at the Crystal Palace, where there was an orchestra capable of accommodating 4,000 performers. In the Handel Festivals a very good fine quality of sound was produced, with great distinctness; and, if well placed, nearly facing the orchestra, and at a sufficient distance, they would hear very well. Mr. Statham had pointed out the great inconvenience of flat floors for music, as the floor should be gradually raised for the audience. They must all feel very much indebted to him for the suggestions he had made; and he hoped that when the Paper was printed the illustrations which he had exhibited would be introduced.

Mr. Roberts said that the Paper opened up a large number of topics which it was impossible at that hour to enter into. He had felt some surprise that Mr. Statham, in referring to the oval and circular forms of building, had omitted to state that the circular form was the worst for music, unless a variety of things were introduced for the purpose of deadening the sound, such as boxes and draperied hangings. The circular form, in fact, constituted a whispering-gallery, and a building of that shape was more suited for spectacles than for music. He could well undersand, as mentioned by General Scott, that music could be heard so much better in the Albert Hall when there was a forest of scaffolding in the building; and if means were taken to prevent the reverberation of sound it might become a capital place for music. In the performance of music at the Crystal Palace there was this peculiarity, that the music never followed immediately upon the baton. The majority of singers there, instead of following the baton, followed the sounds which came back to them, and there was thus a dragging in the music. Reverting to the shape of the Hall, the best room, in his opinion, for

music was at the Hanover Square Rooms; the sides were unbroken, and there was a gallery, but not a coved ceiling. In regard to the Albert Hall, he might mention that he had frequently been there to test its acoustic properties, and he observed that the sound appeared to perform a curve, and when it departed from that curve the sound fluttered and the music seemed out of tune, although the performers were singing in tune. He could not state the amount of variation, but was able to attest the variation by personal observation. He seconded the vote of thanks.

Mr. Seddon wished to say a word as to the position of organs in churches. He was surprised to hear Mr. Statham suggest a transept as the best place, for in that situation the organ would be likely to speak to the wall. He had noticed this effect in the organ of Great Yarmouth Church, which had been placed, against his advice, in the transept; although in this particular case he said it would perhaps do there if it could do at all in such a situation, because of the enormous size of the arches, which would enable the organ to speak right and left. The ordinary method of putting the organ into a box could not be right.

The vote of thanks having been put from the chair and carried,

Mr. Statham acknowledged the compliment, and replied to various points raised in the discussion. He said that he had never been to one of the Handel Festivals, but the result had been described to him as less effective than they could expect from so large a number of performers. He was thereby confirmed in the impression that these large performances were not successful for the realization of music as a language. With respect to the circular form, he thought that the roof should not be an exact circle, but be broken up into panels. He would have much more confidence in building a small room circular than a large room. In the Hanover Square room the audience was placed in the middle, and it was a square room. With respect to placing the organ in the transept, he contemplated a very shallow transept, not a deep one. His opinion was that it should be placed at the end of a church, but considerations of ritual were involved, which could not be entered into. It was important for the band to be near the conductor, as his relation to them was nearer than to the chorus.

ON THE HARDENING, TEMPERING, DRAWING AND WELDING OF STEEL.

From "Die Metallurgie," through "Iron Age."

CASE-HARDENING.

In many cases it is customary to convert only the surfaces of wrought-iron articles into steel, as well as to impart to steel a greater superficial hardening than it receives throughout, so that it may wear better or be better fitted for polishing. The process by which this is accomplished is similar to the converting process, but differs essentially from it in one respect: that a carbonization, not penetrating deeply, is accomplished as rapidly as possible. Different materials are used for this purpose, such as animal coal from bones, leather, horn, etc., soot, which contains small amounts of ammonia-salts, substances containing or forming cyanogen, especially yellow prussiate of potash. Of other nitrogenous bodies used, we may mention nitre, urine or excrements of birds, which latter are distinguished for a large amount of urates.

A very common process consists in imbedding the articles in a sheet-iron box in animal coal, either by themselves or with charcoal powder, and then heating them for an hour, either in a simple hearth or in a charcoal fire, and then cooling in water. Quite often the pieces are only covered with the hardening substance. By using yellow prussiate of potash, it is sufficient to heat them to a yellow red heat, to spread the finely pulverized salt upon them, and to cool in water as soon as the former is melted on the surface. If the substances are less easily fusible, it needs a binding material, such as glue-water or beer yeast, in which the tools are first immersed; the hardening powder is then spread upon them, when they are dried and heated to glowing. Rinmann, who made many experiments in case-hardening, recommends a mixture of 12 parts of soot, 8 of burned horn, 10 of black flux (obtained by detonating equal parts of cream of tartar and nitre), and 28 parts of

chloride of potassium. In Sheffield, Martignoni recommends 5 parts pulverized ox-hoofs, 5 Peruvian bark, 2½ salt, 2½ yellow prussiate of potash, 1½ nitre, 10 green soap. The piece to be hardened is covered with it while red hot, whereupon it is again heated to a dull redness. After this it is cooled in water, annealing being unnecessary. The expensive Peruvian bark, according to Martignoni, serves only as binding material, and might in all cases be replaced by other and cheaper materials. H. Vaughn immerses wrought iron articles into a glowing liquid bath of 25 parts prussiate of potash, 65 parts salt and 10 parts bichromate of potash, to which powdered horn or animal charcoal has been added. The articles are hardened in water. For hardening and annealing steel, he uses a bath consisting of 4 parts prussiate of potash, 12 salt and 2 bichromate of potash. For polished steel, which would be injured otherwise, he replaces the chromate of potash partly or wholly by a mixture of equal parts they use for hardening files, according to Dittmarr, a mixture of 16 parts coal obtained by carbonizing waste from hoofs, horn or leather, 2 oven-soot and one part salt. From this a paste is made by the addition of some clay, water, vinegar or beer yeast. With this paste the files are covered, dried in warm air, heated to a cherry red, and hardened in a solution of salt. They are then pickled in diluted oil of vitriol, brushed and oiled, after having been dried in hot air. Eckmann says that steel obtains a very hard surface if the hardening powder intended to be used is mixed with a solution of arsenious acid in muriatic acid, as then, in glowing, a brilliant white layer of an alloy of iron and arsenic is formed, which is very little exposed to rusting.

Among the many means recommended for case-hardening, the following deserve mention: Potash and borax. Wrought iron and cast iron can be hardened, according to Johnson, if dipped for a few minutes in a heated condition into a bath of 50 parts fat, 50 oil, 35 charcoal, 25 yellow prussiate of potash, 33 horn and 30 nitre. Karmarsch mentions that the points and edges of tools (pointed hammers, etc.) may be hardened by sticking them, when bright red, for a moment into a paste of 1 part prussiate of potash, 1 part potash, 2 green soap, 2 lard or tallow, and then cooling them in water.

Another recipé, which, however, was known to Agricola (1561), prescribes the dipping of the welding-hot wrought iron into molten pig iron, a few moments being sufficient to produce a cementation of the thickness of a line. A similar result may be attained by rubbing over the iron to be hardened, while white hot, with a piece of strongly heated cast iron, or by turning it in filings of gray cast iron and then by cooling it.

The process of case-hardening has not been confined to small articles, but has also been confined to small articles, but has also been applied to large ones, such as rails, tires, and parts of machines, by cementing them in specially constructed furnaces or in boxes of proper form. This operation requires from 6 to 48 hours, according to the depth to which the carbonization is to penetrate and to the cementing material applied. Recently this method has lost in importance, because most articles are now made of steel, instead of wrought iron. In consequence of a long subjugation to great heat, case-hardened articles assume a coarse, crystalline texture and then get brittle. This change, according to Carre, can be obviated entirely if the articles, when withdrawn from the cementation-boxes, are heated as quickly as possible to the highest temperature which they attained by cementation, and then allowed to cool in the air. The hardening is then accomplished in the ordinary manner.

DRAWING OF STEEL.

If steel is drawn down at a proper temperature and skilfully, a certain form corresponding to a further application may be given to it, while, at the same time, its quality can be materially improved. By hammering, the grain becomes firmer, the density increases, and, in fact, the steel attains only in consequence of these operations the highest degree of tenacity and solidity, as may readily be witnessed by the changed appearance of the fraction of unhammered and hammered steel, as well as by the considerable increase of the specific weight. The latter was, according to Schafhantl, 7.698 when the steel was not hammered, 7.767 after hammering in the heat, and 7.87 after hammering cold. Caron has shown that, aside from these physical changes, chemical changes take place, since free carbon passes over into the combined state, and that thus a similar, only not so complete a change takes place as in hardening. Caron analyzed three specimens of

cementation-steel, of which the first had been directly withdrawn from the converting chest, the second hammered for some time, and the third hardened. After having been treated in the same manner with muriatic acid, it was found that the residue of 100 grammes

	Residue, Grammes.
Cementation-steel from the converting-chest consisted of	1.624
Cementation-steel hammered	1.243
" " hardened	0.240

These residues contained—

	Not Hammered.	Hammered.	Hardened Steel.
Carbon	0.825	0.560	trace
Iron	0.557	0.445	trace
Silica	0.242	0.238	0.240
Total	1.624	1.243	0.240

Rolled steel contained a more considerable residue than that which had been hammered; the annealing resulted in this case in an action opposite to that of hammering and hardening, and yielded the more uncombined carbon the longer the heating had lasted.

As to the temperature at which steel is to be drawn down, it depends upon its chemical composition. Several brands, especially those rich in carbon, bear only a comparatively low temperature, which must only reach brown red, and which requires, therefore, much care and patience, while a higher heat can be applied for the brands approaching more the wrought iron. If the temperature falls below a certain limit, the difficulties of the drawing down become always greater, especially with thick pieces, and flaws are easily produced. For these reasons it is not only necessary to determine the temperature for every kind of steel, at which it will draw down best, but also to treat the material rapidly and uniformly. In most cases tilt-hammers are used, making 400 blows in the minute; for larger pieces, as wheel bands, heavy steam hammers, or, in lieu thereof, powerful rollers and hydraulic press hammers are employed. The latter two contrivances offer an advantage, inasmuch as they exert a more uniform pressure, communicating itself to the interior, whereas by the short blows of a hammer the surface is more drawn down than the centre, as may be easily observed at the concave form of the ends of cylindrical pieces thus treated.

Although the hammering of steel in the cold state offers particular difficulties, it is nevertheless applied for various hardened, as well as not hardened articles, because their density, hardness, tenacity and elasticity are thereby considerably increased. The hammering in the cold is, for instance, used for watch springs annealed blue, for the edges of scythes and sickles, partly in their manufacture, partly by the reapers themselves, when they beat them out with a small hammer before sharpening; again, it is done with the edges of razors, fine chisels, etc. Articles are also hammered cold, in order to straighten them; but it is evident that in all these cases the work must be done very carefully, and that only a very gradual, and only to small distances, extending motion of the steel molecules can take place.

THE WELDING OF STEEL.

The property of weldability, as well known, is possessed by wrought iron—not, however, by pig iron; hence it is evident that steel must exhibit a very different deportment in this respect, according as it approaches in its composition the one or the other. Many kinds of steel of a low percentage of carbon weld almost as easily as wrought iron; others of a higher percentage weld with more difficulty; while, finally, pig iron, which is rich in carbon and for which the degree of softening and that of melting are near each other, can either not be welded at all, or only by particular means. Not only does the absolute amount of carbon in the steel determine weldability, but also the manner in which it is distributed through it. Crude steel and steel of cementation weld easier than cast steel which is prepared from the former by remelting, although this latter has rather undergone a diminution than an increase of the amount of carbon. Cast steel gains for the same reason in weldability, when made to glow for some time under exclusion of air and then allowed to cool slowly, whereby, as well known, a partial separation of chemically combined carbon takes place.

Steel requires a lower welding heat than wrought iron, but if exposed to too high a temperature, it burns, and, in consequence, becomes so friable that it breaks to pieces when hammered. This circumstance is to be taken into consideration in welding steel

and wrought iron, which is so often done with tools, anvils, rails, etc. This operation is partly executed in order to produce the articles cheaper, partly to give to the parts most exposed to wear the hardness of steel, and to others the tenacity and infrangibility of wrought iron. In this case the wrought iron is first placed into the fire or both are heated separately; besides, particular fluxes are applied for the purpose of protecting the steel from burning, and to facilitate the unification of the various materials. The most essential conditions to be fulfilled in welding are, that the pieces to be welded possess a pure metallic surface, and that they be properly formed in the first instance, so that they may be united without delay. Where it can be done, they are put together as well as possible before they are placed in the fire. The steel must be heated as rapidly as possible and excluded from the air; best with charcoal and good coke, since coals, on account of the fact that they contain sulphur, produce a thin layer of sulphate of iron, which prevents proper welding. In order that the parts to be welded may remain pure in the fire, they are covered with a proper material, which forms a liquid, protective layer, and at the same time dissolves the oxide. For this purpose sand or clay is used, by spreading them upon the parts in form of a paste; the operation succeeds much surer and easier with less fusible coverings. For cast steel, ground glass, heavy spar, or anhydrous molten borax serve well. Hustig says that for English cast steel, common builders' mortar may be used, or, in lieu thereof, a mixture of clay and sand.

Aside from these more simple means, special welding powers are employed, the composition of which permits the formation of an easily fusible slag, which at the same time acts as a carbonizing material. Among the mixtures recommended we mention the following: 64 parts borax, 20 parts sal-ammoniac, 10 parts yellow prussiate of potash, 5 colophony. These ingredients are heated with ½ litre water and some alcohol, until dry. But, since during boiling, borax and sal-ammoniac are converted into boracic acid and common salt, and since the colophony gives formation to a carbonaceous layer, rather preventing the welding, Th. Rust recommends 41.5 parts boracic acid, 3.5 salt, 15.5 prussiate of potash, 8 calcined soda.

Habich prescribes 7 anhydrous prussiate of potash, 2 calcined soda, and more or less burned borax, according to the nature of the steel. Ermer recommends, to dissolve in water, 8 borax, 1 sal-ammoniac, 1 yellow prussiate of potash, and to evaporate the solution at a low heat to dryness. When strongly heated, violent explosions may occur by the formation of chloride of nitrogen. Another method is as follows: Borax is fused with $\frac{1}{10}$ of its weight sal-ammoniac, and to the vitreous mass same quantity of burned lime is added. Still another employs 8 parts heavy spar, 1 gall of glass, and 1 black oxide of manganese.

In welding, at first light, then heavy blows are given, so that the slag may escape from the joints, whereupon the outer surfaces are united. Instead of ordinary hammers, rollers or hydraulic presses are sometimes used. It may finally be mentioned that the coating of large wrought-iron articles with steel, is also accomplished by casting steel around them in proper forms.

BLAST FURNACES.

By M. L. GRUNER, Professor of Metallurgy.

Translated from "Annales des Mines."

(1.)—CHANGE IN THE RÉGIME OF BLAST FURNACES.

For some years past much attention has been given, especially in England, to two important modifications of blast furnaces. These consist in increasing their height and their volume, and in heating the blast to redness by use of great structures of Cowper-Siemens and Whitewell's fire-proof brick. By these means figures have been reached, which many metallurgists, Mr. Lowthian Bell for example, regard as exaggerated, while others admit no limit except that of practical possibility. These differences of opinion are shown in the *reunions* and publications of the Iron and Steel Institute, an association composed of the most noted English iron men, Bessemer, Siemens, Bell, Whitworth, Menelaus, Williams, and others. It is worth while to

discuss the question, and to study the chemical and caloritic reactions operating in these enormous structures. I shall make use of the series of very interesting memoirs which Lowthian Bell has just published in the "Journal of the Iron and Steel Institute," and I shall give an account of my own researches, some of which have for a long time been presented in my course of Metallurgy at L'Ecole desMines de Paris, others having been recently published in the "Recueil des Savants Etrangers," and in the "Annales de Physique et de Chimie."

(2)—PROGRESSIVE ENLARGEMENT.

Charcoal furnaces in our country rarely exceed 10 to 12 metres in height and 20 to 30 cubic metres in interior volume. In Austria, Russia and Sweden, where facilities of transportation permit greater accumulation of fuel, the height has reached 15 metres, and the volume 50 to 60 cubic metres. In the oil districts, blast furnaces have attained greater dimensions; still the ordinary furnaces of Staffordshire measure only 70 to 75 cubic metres, with a height of 12 to 13 metres, and the largest do not exceed 100 to 150 cubic metres. In 1830 their average volume was 50 to 55 metres, while in Wales it was 60 to 70 metres. But in 1860 M. Lan and myself showed that there was a marked tendency to gradual enlargement. In Scotland 90 to 200 metres had been reached, and in Wales 70 to 150 metres, with exceptional cases of 200 to 300 metres. These successive enlargements had for end the increase of production; and we showed that the production sensibly increased with the increase of interior volume.

In the English furnaces, large and small, an average is produced of a ton of pig iron (Nos. 1 and 2) to 7 to 8 metres of interior volume; a ton of grey forge iron (Nos. 3 to 4) to 6 to 7 metres; and a ton of white forge iron (Nos. 5 and 6) to 5 to 6 metres.

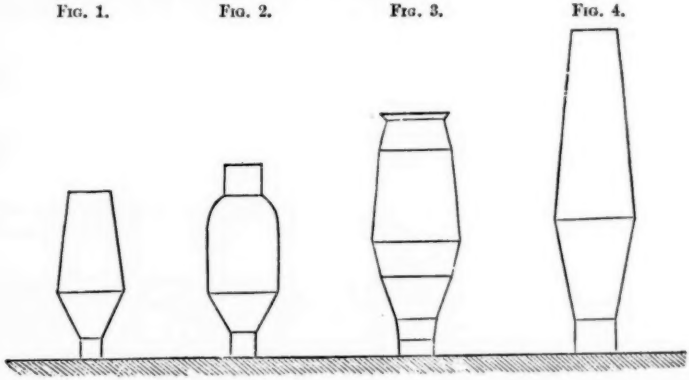
I arrived at the same conclusions upon comparison of a great number of furnaces on the Continent, and in my lectures I pointed out these figures as the proper averages for fixing the dimensions of blast furnaces.

In 1851 the first furnace was built at Cleveland, near Middlesborough. Vaughan & Bolckow gave it a height of 12.80 metres, and a volume of 130 metres. (Fig. 1.)

In 1853 Bell Bros. built the Clarence Works, constructing several furnaces of 14.60 metres, and 175 cubic metres. (Fig. 2.)

From 1853 to 1860 a great number were

FIG. 1. FIG. 2. FIG. 3. FIG. 4.



set up in the same district, but none exceeded 17.50 metres, and 200 cubic metres.

In 1861 appeared a marked tendency to a great enlargement. In this year Whitwell & Co. built at Thomaby three furnaces of 18.30 metres, and 362 cubic metres. (Fig. 3.)

In 1862 Bolckow & Vaughan reached 23 metres, and 340 cubic metres.

In 1864 Samuelson, at Newport, gave to his furnaces the dimensions 21 metres, and 440 cubic metres; and Thomas, at Southbank, 24.70 metres, and 456 cubic metres. (Fig. 4.)

In 1866 Bolckow & Vaughan, at Cleveland, adopted the *elmcés* type of 29 metres, and 430 cubic metres; while Hopkins, Gilkes & Co., at Tees-Side, gave preference

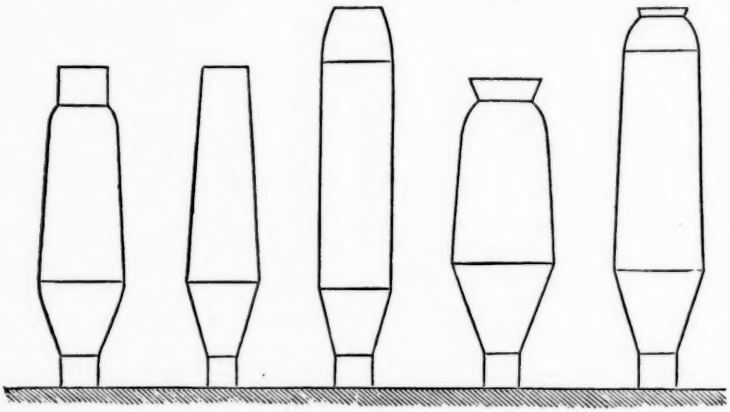
to the broader form of 25 metres height, to 566 cubic metres of volume.

In 1867, at Ormesby, the dimensions were 23 metres, and 584 cubic metres. (Fig. 8.)

In 1868 Bolckow & Vaughan enlarged their furnaces to 736 cubic metres and 815 cubic metres, with a height of 29 metres. (Fig. 9.)

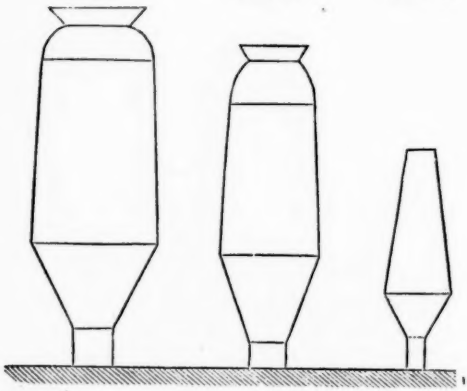
In 1870 Cochrane, at Ormesby, built a monster furnace of 27.50 metres, and 1,165 cubic metres (Fig. 10); while at Ferry Hill was constructed one of 31.50 metres, and 935 cubic metres.

FIG. 5. FIG. 6. FIG. 7. FIG. 8. FIG. 9.



Finally, in 1871 Cochrane gave to his last surface of 1,218 cubic metres volume, to the same height, 27.50 metres. Fig. 5 represents the furnace at Clarence Works (1865), height 24.40 metres; volume 440 metres. Figure 6, at Clarence Works (1866), height 24.40 metres; volume 330 metres. Fig. 7, at Cleveland (1866), height

FIG. 10. FIG. 11. FIG. 12.



29 metres; volume 400 metres. Fig. 11, at Clarence Works (1870), height 24.40 metres; volume 700 metres. Fig. 12, at Pouzin (1857), height 16.90 metres; volume 115 metres.

The interior profiles of most of these furnaces given in the figures are from the historic account of Mr. J. Gjers. The forms are various, ranging from slender profiles (*elancés*) almost cylindric, to shafts singularly squat (*trappues*), swelling at the middle and contracted above. These forms

have a certain influence upon the operation of the furnaces. Unfortunately the brief notice of Mr. J. Gjers does not give details, even in respect to maximum production. But I have been able to supply this deficiency from data furnished in the memoirs of Bell, and the reports of the discussions of the Iron and Steel Institute. That which first compels our notice is that the production of large furnaces does not increase proportionally with the volume. Thus, at the Clarence Works, we find the following productions for four very different types of dimensions giving forge iron Nos. 3 and 4.

ELEMENTS.	Old furnace of 1853.	Blast furnace of 1866.	Blast furnace of 1865.	Blast furnace of 1870.
Total volume	170 m.	330 m.	440 m.	700 m.
Height	14.60 m.	24 4 m.	24.4 m.	24.4 m.
Production in 24 hours	30 t.	38 6 t.	50 t.	60 t.
Coke consumed per ton of product	1.450 kil.	1.125 kil.	1.125 kil	1.125 kil.
Interior volume to ton in 24 hours	5.6 m.	8.6 m.	8.8 m.	11.7 m.

On the other hand the numerous furnaces of Bolckow & Vaughan and those at Ferry Hill, fed by the same minerals and coke as those of the Clarence Works, but with the blast heated to a temperature of 400 deg. to 500 deg. C. (the iron being Nos. 3 and 4), give the following results:

ELEMENTS.	Built 1864.	Built 1868.	Old blast furnace at Ferry Hill.	New blast furnace at Ferry Hill.
Total volume	430 m.	736 m.	453 m.	935 m.
Height	29 m.	29 m.	24.4 m.	31.5 m.
Production in 24 hours	46 t.	52 t.	50 t.	78 t.
Coke consumed, per ton	1.125 kil.	1 125 kil.	1.025 kil.	1000 ?
Interior volume to ton in 24 hours	9.3 m.	14 m.	9 m.	12 m.

Finally, comparing the three types successively employed by Samuelson at Newport we find the following results:

An old furnace of 144 m. produced 23 t. in 24 hrs., or 6 3m. per ton.
A second (1864) of 440 m. produced 45 t. in 24 hrs., or 9 m. per ton.
The last, of 850 m. produced 70 t. in 24 hrs., or 12 m. per ton.

Mr. Bell remarks that in no case in Cleveland, did a furnace of 25,000 cubic feet produce twice as much as one of 12,000 cubic feet.

We observe that in the old furnaces of 150 to 200 metres, the mean volume is 6 metres per ton of Nos. 3 and 4, while in modern blast furnaces of 300 to 450, it is 8 to 9 metres; and in the most recent, of 700 to 1,202 metres, it is 12 to 14 metres.

In other words, the descent of charges requires 60 to 70 hours in large furnaces, and only 30 to 40 in smaller.

This extreme slowness of descent may be a real advantage in one point of view. It may be that the reduction takes place under more favorable conditions, so that the mineral reaches the belt of fusion in a better state of preparation. But is there any limit to the progressive enlargement of blast furnaces? Is there not an exact mean corresponding to a maximum of economy? In a process too slow is not the carbonic acid produced in the reduction of the mineral ready to form, by contact with the incandescent carbon, oxide of carbon with a rapidity proportional to the slowness of descent? In a word, is not the consumption necessarily less in proportion to the magnitude of the furnace?

The results just given already partly answer this question. Before 1860, in the blast furnaces at Cleveland, there was consumed 1500 to 1700 kilograms of coke per ton of grey forged iron; or at the least 1450 kilograms, according to the recent data of Bell. To-day, in large furnaces, the consumption is 1125 kilograms, with blast at a temperature of 400 deg. to 500 deg C. But it is certain that in this respect there is no difference between furnaces of 300 to 500 cubic metres, and those of 800 to 1000 cubic metres.

If, then, beyond certain limits large furnaces do give a greater product, and if they do not use less coke than those of moderate dimensions, it does not seem rational to build monster furnaces. This seems to be realized by our neighbors. A certain reaction already appears in England among forge masters, at least in the districts where fuel and the mineral are more or less subject to break or compress under their own weight. At Askam-in-Furness they have gone back from a height of 75 feet to 61; at the Consett Works from 70 to 55; at Workington from 70 to 55; at Barrow from 75 to 61; and at Creuzot a furnace has just been cut down 25 metres.

These examples are sufficient to show that a great height may be attended with real disadvantages. But if we would appreciate the exact influence of these increased dimensions we must take an exact account of the chemical and calorific reactions that occur in the furnace.

(3)—REACTIONS IN BLAST FURNACES.

Two inverse currents react upon each other: an ascending current of gas, of which the temperature is at first very high, and decreases gradually to the mouth; and a descending solid composed of mineral, fuel, and smeltings, whose temperature increases on account of the influence of the counter current of gas. One of these currents is very slow, the other very rapid. The solids seldom descend with a velocity greater than half a metre per hour, while the gas traverses the same space in less than a second. Besides, the mass of air injected into a blast furnace is generally more than that of the solid matters introduced during the same time; and the weight of gas discharged is often more than double that of the smelted products that escape at the lower orifices.

The air, forced into furnaces at the bottom by blowers, is almost immediately transformed into oxide of carbon; then this gas, in its passage reduces the mineral more or less directly; that is to say, either with or without the aid of solid carbon.

The reduction of the oxide of iron in the blast furnace may be accomplished in three different ways, generally, the oxide of carbon is transformed into carbonic acid, which escapes without further reaction. Besides this, the carbonic acid thus produced partially reforms oxide of carbon in burning the solid carbon; this leads to the same result as if the solid carbon were to act directly upon the oxygen of the mineral, to yield, in the last analysis, either carbonic acid or the oxide of carbon.

These three methods of reduction can be represented by the following formula:

$$(1.)\ 3\,C\,O + Fe^2\,O^3 = 3\,C\,O^2 + 2\,Fe.$$
$$(2.)\ 3\,C + 2\,Fe^2\,O^3 = 3\,C\,O^2 + 4\,Fe.$$
$$(3.)\ 3\,C + Fe^2\,O^3 = 3\,C\,O + 2\,Fe.$$

It should be observed that the two first modes of reduction would not, in principle, be realizable if the proportions given in the formulas were adopted. In these conditions the metallic iron would be partially re oxidized by the carbonic oxide. The experiments of Debray (confirmed by those of Lowthian Bell) prove that in presence of equal volumes of C O and $C\,O^2$, the peroxide and the metallic iron are both brought to the condition of the protoxide. But if the two first methods are practically impossible when taken separately, they, with the third mode, contribute to the final result, and the gases at the mouth are always found compounded of a variable mixture of C O and $C\,O^2$. According as one or the other of the methods has the larger part in the final result, we find at the mouth greater or less proportions of carbonic acid or of oxide of carbon. It is easy to show that the three methods require very different qualities of heat; and that in this point of view, it is not indifferent whether one or the other of the reactions predominates in blast furnaces.

(4)—QUANTITY OF HEAT ABSORBED AND DISCHARGED.

Let us find the heat absorbed and discharged in the three modes of reduction.

The heat absorbed is the same in the three cases. It is that quantity which a kilogram of oxygen would generate in combining with the metallic iron to form the peroxide. Denote this number of heat-units by C.

In the first case, the heat results from the change of C O to $C\,O^2$. Now, each kilogram of oxide of carbon produces 2403 heat-units in yielding to the oxide of iron $\frac{4}{3}$ kilograms of oxygen; hence, for each kilogram of oxygen the transformation of C O to $C\,O^2$ is accompanied by a production of heat of $\frac{3}{4} \times 2403 = 4205$ heat-units. Thus the difference C – 4205, represents the heat required to each kilogram of oxygen for the reduction of the peroxide of iron, under the action of the oxide of

carbon passing to the state of carbonic acid.

In the second case, the solid carbon is transformed to CO^2 by the oxygen of the mineral. In these conditions, a kilogram of carbon develops 8080 heat-units in taking up $\frac{8}{3}$ kilogram of oxygen, which gives, per kilogram of oxygen, $\frac{3}{8} \times 8080 = 3030$ heat-units. Hence, $C - 3030$ is the heat necessary for reduction, when it operates by means of the solid carbon yielding carbonic acid.

Finally, in the third mode of reduction, the process is as if the oxygen of the mineral directly produced oxide of carbon with the solid carbon. A kilogram of carbon generates 2473 heat-units when it is transformed into oxide of carbon, and as it then takes up $\frac{4}{3}$ kilogram of oxygen, the heat generated by each kilogram of oxygen is $\frac{3}{4} \times 2473 = 1855$ heat-units. Consequently, the difference $(C - 1855)$ is the number of heat-units which the reduction requires when it is accomplished by the solid carbon yielding oxide of carbon.

Hence, in order to yield to the peroxide of iron a kilogram of oxygen, the following quantities of heat are necessary:

$C - 4205$ h. un.
$C - 3030$ "
$C - 1855$ "

The value of C is not exactly known; it may vary with the nature of the peroxide: but in all cases it would seem to lie between 4000 and 5000 heat-units, so that the first mode of reduction acts almost without loss of heat. Again, whatever the value of C, this mode is much the most favorable, and the last is very laborious. It is of importance, then, that reduction should be made by the first method as far as possible—that is, by the oxide of carbon yielding carbonic acid; in other words, *without consumption of solid carbon.* I shall call this the *ideal* operation of blast furnaces.

In order to realize this *ideal* action, or to approach it as nearly as possible, the reduction should take place in a part of the furnace in which the temperature is relatively low, otherwise the carbonic acid generated would constantly re-form oxide of carbon at the expense of the solid carbon. The furnaces should be large enough, or high enough, so that all the upper portion may be at a relatively low temperature; and it is also necessary that the motion of the gas shall be so rapid as to leave the carbonic acid in contact with solid carbon for a short time only. And it is obvious that those minerals which are easy of reduction will realize the ideal process more nearly and readily than those that are compact and silicious. But in general, whatever the mineral may be, complete reduction will take place only in the warm regions, where the carbonic acid continually reproduces the oxide of carbon, and this occurs in all parts for all oxides except that of iron, due to the oxidation of silica, chalk, magnesia, and the oxide of manganese. The reduction of these oxides always requires contact, direct or indirect, with solid carbon.

(5)—THE ACTION VARIES WITH THE RATIO $\frac{CO^2}{CO}$.

From what precedes, it follows that the relative quantities of carbonic acid and of oxide of carbon at the mouth depend essentially, for a given bed of fusion, upon the mode of reduction; hence, a greater or less ratio gives a means of determining the degree of perfection in the action of a blast furnace. An example or two will serve to show this.

We shall soon see that, for the same furnace with the same minerals and same product, the temperature of the blast being constant, the ratios are as follows, regard being had to the dimensions and profile of the furnaces:

0.3 of total carbon, under the form CO^2
and
0.7 of total carbon under the form CO

giving a ratio $\frac{CO^2}{CO} = 0.673$, or, in the case of less economy

0.2 of total carbon, under the form CO^2
0.8 " " " CO,

giving a ratio $\frac{CO^2}{CO} = 0.392$.

Let us calculate the heat produced. In the first case we have

$0.3\,k. \times 8080 + 0.7\,k. \times 2473 = 4155$ heat units;

in the second

$0.2\,k. \times 8080 + 0.8\,k. \times 2473 = 3594$ " "

Difference..... 561 " "

To obtain the same products the same amount of heat is required; consequently, each kilogram of carbon burned in the first furnace, should be replaced in the second by $1\,k. \times \frac{561}{3594} = 1.155$ k., corresponding to

an increase of consumption of 15 to 16 per cent., due solely to the production of less carbonic acid, or to the more energetic action of the gas upon the solid carbon in the heated portions.

Let us now compare a *good* with an *ideal* action, regarding as *good* that which corresponds to the above ratio of $\frac{C\,O^2}{C\,O} = 0.673$. This is the case with the better blast furnaces at Cleveland, when account is taken of the gas from the coke and that from the lime flux. Suppose, as is the fact at Cleveland, that for each kilogram of product the actual consumption is 1 kilogram of carbon and 0.60 of lime flux. With these data we calculate the weight of carbon contained in the gas, to each kilogram of product.

The coke yields to the iron 0.03 kilogram of carbon. The 0.60 kilogram of limestone flux contains $0.60 \times 0.12 = 0.072$ kilogram of carbon. Hence the gases will contain, per kilogram,

0.970 k. of carbon from the coke.
0.072 k. " " " limestone.

Total... 1.042 k.

Now, as the ratio above of $\frac{C\,O^2}{C\,O} = 0.673$ corresponds to 0.3 of carbon in the state $C\,O^2$; for 0.7 of C O we have, in the gas at the mouth,

0.3×1.042 k. $= 0.3126$ k. of carbon as $C\,O^2$
0.7×1.042 k. $= 0.7294$ k. " " C O

1.0420 k.

But, of the 0.3126 kilogram of carbon contained in the carbonic acid, the limestone furnishes 0.072 kilogram. There remains, furnished by the coke,

0.3126 k. $- 0.072$ k. $= 0.2406$ k.,

which gives as total heat produced by combustion to each kilogram of product:

$0.2406 \times 8080 = 1944$ heat-units
$0.7294 \times 2473 = 1804$ " "

Total..... 3748 " "

This same quantity of heat should be generated in the *ideal* action; supposing, for sake of simplicity, that in the two cases the hot blast furnishes an equal number of heat units, and that the gases furnish the same amount of sensible heat. The *ideal* process assumes that the reduction of oxide of iron is caused only by the oxide of carbon, without intervention of solid carbon.

Now, it is easy to calculate the weight of oxide of carbon transformed into $C\,O^2$ by the reduction of the mineral; at least if we take into account only the oxide of iron properly so called. To the kilogram of product, there are in the oxide of iron 0.97 kilogram of iron and 0.97 kilogram $\times \frac{3}{7}$ of oxygen; and this oxygen transforms into $C\,O^2$ a weight of C O containing a quantity of carbon equal to three quarters of its weight of oxygen, or

$$\tfrac{3}{4} \times \tfrac{3}{7} \times 0.97 \text{ k.} = 0.312 \text{ k.}$$

The heat produced by this carbon in its transformation into oxide of carbon near the blast pipe, and into carbonic acid in the zone of reduction, is

0.3120 k. $\times 8080 = 2521$ heat units;
hence the oxide of carbon furnishes 1227 " "

Total..... 3748 " "

These 1227 units require the burning of $\frac{1227}{2473} = 0.496$ kilogram of carbon.

This gives, finally, for total consumption

$$0.030 \text{ k.} + 0.312 \text{ k.} + 0.496 \text{ k.} = 0.838 \text{ k.}$$

instead of 1 kilogram; or, in the case of *ideal* process, a saving of 0.612 kilogram, per kilogram of product.

Finally, the relative quantities of oxide of carbon and carbonic acid in the *ideal* action are as follows:

0.312 k. + 0 072 k.
(limestone) = 0 384 k. of carbon in $C\,O^2$.
and 0 496 k. " " C O.

Total carbon in gas 0.880 k.

hence

$$C\,O^2 = \frac{11}{3} \times 0.384 = 1.408 \text{ k.}$$

and

$$C\,O = \frac{7}{3} \times 0.496 = 1.157 \text{ k.}$$

$$\therefore \frac{C\,O^2}{C\,O} = 1.217.$$

(6)—THE RATIO $\frac{C\,O^2}{C\,O}$ IS THE MEASURE OR INDEX OF THE ACTION OF BLAST FURNACES.

I have just shown that the ratio $\frac{C\,O^2}{C\,O}$ may vary between limits wide apart. In the modern works at Cleveland it is generally between 0.50 and 0.60 in case of favorable process; it is 0.350 to 0.400 only when the conditions are bad; it would reach 1.217 if the action were *ideal*.

We perceive that this ratio is a measure or index of the degree of perfection of action in the blast furnace. This will vary in different districts according to the quality of

the mineral, the kind and purity of the fuel, the proportion of flux employed, the number of the product, etc. But at the same works, or in a given district, this ratio will rise or fall, approaching towards or receding from the *ideal* ratio. It is, therefore, important to determine this ratio exactly by trials easily multiplied. When the ratio is known, the absolute quantities of the two gases can be easily calculated, and the amount of heat due to the combustion of fuel.

It remains to show that the fixing of this ratio not only enables us to fix rigorously the absolute quantities of oxide of carbon and carbonic acid, but also to determine very closely the weight of blast and of gas, and their composition.

(7)—WEIGHT AND COMPOSITION OF GAS AT THE MOUTH.

The ordinary, or normal action of a blast furnace makes known the weight of burnt carbon and of limestone consumed per kilogram of product. The quality of the product gives the proportion of carbon in the iron. This is about $\frac{3}{100}$ in the ordinary product.

Let a = carbon per kilogram of product.
b = carbon yielded by flux.
$\therefore p = a + b - 0.03$ kilogram = total carbon.
y = weight of C O.
$m = \frac{C O^2}{C O}$.

Then $m\,y$ = weight of $C O^2$, hence

$$\frac{3}{7}y + \frac{3}{11}m\,y = p,$$

a formula which signifies that the quantities of carbon contained in C O and $C O^2$ are equal to the total carbon in the gas. The equation gives

$$y = \frac{77\,p}{33 + 21\,m}.$$

The oxygen contained in the gas is equal to the oxygen furnished by the blast and the bed of fusion; as expressed in the equation

$$\frac{4}{7}y + \frac{8}{11}m\,y = d + x$$

in which x represents the oxygen furnished by the blast, and d the amount taken from the mineral and the carbonic acid of the flux. From this equation we find

$$x = \frac{y}{77}(44 + 56\,m) - d$$

$$x = \left(\frac{44 + 56\,m}{33 + 21\,m}\right)p - d.$$

To obtain the value of x, the value of d must be known. If the oxide of iron alone were reduced, it would be easy to calculate d exactly. It would be composed of two terms—the oxygen combined with b of carbon (in the carbonic oxide of the flux), or $\frac{8}{3}\,b$; besides the oxygen combined with the

$$0.97 \text{ k. of iron; or } \frac{3}{7} \times 0.97 \text{ k.},$$

if the iron is in the condition of peroxide; so that we have

$$d = \frac{8}{3}b + \frac{3}{7} \times 0.97 = \frac{8}{3}b + \frac{2\,91}{7}$$

But in general the run includes, besides the iron and 3 per cent. of carbon, other elements, such as silicium, manganese, etc. But if the composition of the product is known, it is as easy to calculate the oxygen furnished by the various elements as that furnished by the oxide of iron.

If we neglect this correction we generally find a value for d a little too small; for this amounts to an assumption that these foreign elements are found combined in the same proportion in oxygen as in iron, while at least the silica furnishes too high a proportion.

Taking the mean composition, we can at least approximate the truth and obtain for d and for x numbers differing little from their real value. Suppose a run of grey force *(fonte grise)* or Nos. 3 and 4. We may assume for mean composition of products containing little manganese:

Iron	0.94
Carbon	0.03
Silicium, etc	0 02
Earthy minerals, etc	0.01
	1.00

With these equivalents the silica contains 24 of oxygen to 21 of silicium; hence the oxygen from the silica is $\frac{8}{7} \times 0.02$ kilograms; and this expression would give an approximate value for the oxygen even if the silicium were in part displaced by phosphorus or sulphur; since the phosphoric acid contains 5 of oxygen to 4 of phosphorus, and the sulphuric acid 5 of oxygen to 2 of sulphur. As to the earthy constituents, we know that

In limestone the oxygen corresponds to	2-5	of the	metal.			
In magnesia	"	"	"	2-3	"	"
In alumina	"	"	"	6-7	"	"

We may assume as approximate mean,

$\frac{5}{7}$ of 0.01 kilogram. In all cases the possible error would be insignificant. The corrected value of total oxygen furnished by the bed of fusion would be:

$$d = \frac{8}{3}b + \frac{3}{7} \times 0.94 + \frac{8}{7} \times 0.02 + \frac{5}{7} \times 0.01.$$

$$(3) \text{ or } d = \frac{8}{3}b + \frac{1}{7}(2.82 + 0.16 + 0.05),$$

instead of the preceding expression

$$\frac{8}{3}b + \frac{1}{7}(2.91).$$

The value of x is now found, and we have for the weight of the air itself $4.33\,x$, and for that of the nitrogen $3.33\,x$.

We have supposed the air in the flues perfectly dry, while in fact it is always more or less charged with water, so that the oxygen of steam is added.

The equation

$$\frac{4}{7}y + \frac{8}{11}my = d + x$$

therefore gives for x the oxygen both of air and of water; but it is easy to find the values in case of dry air.

At a mean temperature of 12 deg. to 13 deg. C., a cubic metre of air contains from 4 to 12 gr. of water. Taking a mean of 8 gr., we have for the moisture in a cubic metre of air that weighs 1300 gr., $\frac{8}{1300} = 0.0026$ gr. of pure dry air, and for the oxygen $\frac{8}{9}$ of $0.0062 = 0.0055$ of dry air.

Denoting by z the weight of oxygen furnished by dry air, and by $4.33\,z$ that of the dry air itself, we have

$$x = z + 0.9055 \times 433\,z = (1 + 0.0238)\,z$$

$$\therefore z = \frac{x}{1+0.0258} = 0.97677\,x;$$

hence, for the weight of nitrogen $3.33 \times 0.97677\,x$
" " " dry air $4.33 \times$ "
" " " moist " $4.33 \times$ "
or, " " moist " $4.33 \times 0.9828\,x$.

Although this indirect method is not rigorously exact, since it depends upon a theoretic analysis of the run, yet it is not much less exact than any other. And it can be made as exact as possible by a previous analysis of the actual composition of the product.

(8)—AGREEMENT OF FORMULAS WITH THE COMPLETE ANALYSIS.

From the preceding, the conclusion is, that to determine the composition of the gas at the mouth, it is sufficient to know the ratio $\frac{CO^2}{CO} = m$. The exact quantities of carbonic acid and of oxide of carbon, and a very approximate value of the nitrogen may be calculated; and also the weight of the blast. In fact, only the hydrogen is neglected. But in furnaces working with coke its operation is almost null. The hydrogen can come from only two sources—the moisture of the blast, and that of the hydrocarburetted gas which the partly burned coke contains. But this hydrogen is but a small percentage, and it acts with the oxide of carbon to reduce the oxide of iron. It reforms watery vapor in the upper portions of the furnaces. Only a fraction escapes with the gas without being oxidized. Bell has never found (at Cleveland) more than 0.001 of hydrogen; and Ebelmen not more than 0.0013 to 0.0018 at Vienna, Pont Evêque and Seraing.

This slight percentage is without effect upon the working of the furnace, and may always be neglected in practical calculations, such as those here occupying our attention.

Two examples will show the agreement of the above results with the experiments of Bell.

The first is that of the furnace at the Clarence Works (1853; see § 2, *ante*), of which the height is 14.60 metres, and the capacity 170 cubic metres. The consumption of coke per kilogram of product, is 1.450 kilogram, or 1.318 kilogram of pure carbon and 0.800 of limestone flux.

We have by the formulas of (7)

$a = 1.318$ k.
$b = 0.12 \times 0.80$ k. $= 0.096$ k.
$p = 1.318$ k. $+ 0.096$ k. $- 0.03$ k. $= 1.384$ k.

On the other hand the analysis of the gas gives

CO^2	$= 11.80$
CO	$= 30.50$
Az	$= 57.60$
H	$= 0.10$
	100.00

Hence

$$\frac{CO^2}{CO} = m = \frac{11.80}{30.50} = 0.387.$$

$$CO = y = \frac{77 \times 1.384}{33 + 21 \times 0.387} = 1.002 \text{ k.}$$

$$d = \frac{8}{3} \times 0.096 + \frac{1}{7}(3.03) = 0.256 + 0.423 = 0.679 \text{ k.}$$

$$x = \frac{2.591}{77}(44 + 56 \times 0.387) - 0.676 = 1.531 \text{ k.}$$

$$z = 0.97677 \times 1.531 = 1.495 \text{ k.}$$

$$\text{nitrogen} = 3.33 \times 1.495 = 4.978 \text{ k.}$$

Hence the following quantities of gas

$$\begin{aligned} C\,O^2 &= 1.002 \text{ k.} \\ C\,O &= 2.591 \\ A\,z &= 4.978 \end{aligned}$$

Weight of dry gases = 8 571 k.

while the complete analysis above mentioned gives the following figures:

$$\begin{aligned} C\,O^2 &= 1.002 \text{ k.} \\ C\,O &= 2.591 \\ A\,z &= 4.893 \text{ (difference 0.085).} \end{aligned}$$

8.486

The second example is that of the blast furnace at the Clarence Works (1866; see (2) *ante*), of height 24.4 metres, and of capacity 330 cubic metres.

The consumption per kilogram of product is 1.125 kilogram of coke and 1.020 of pure carbon, and 0.683 of limestone flux. This leads by the formulas of (7) to the values:

$$\begin{aligned} a &= 1.020 \text{ k.} \\ b &= 0.12 \times 0.685 = 0.082 \text{ k.} \end{aligned}$$

hence

$$p = 1.020 + 0.082 - 0.03 = 1.072 \text{ k.}$$

On the other hand the analysis of the gas gives

$$\begin{aligned} C\,O^2 &= 17.30 \\ C\,O &= 25.20 \\ A\,z &= 53.40 \\ H &= 0.10 \end{aligned}$$

100.00

whence

$$\frac{C\,O^2}{C\,O} = m = \frac{17.3}{25.2} = 0.6865$$

$$C\,O \text{ or } y = \frac{77 \times 1.072}{33 + 21 \times 0.6865} = \frac{82.5440}{47.4165} = 1.740 \text{ k.}$$

$C\,O^2$ or $m\,y$ $1{,}740 \times 0.6865 =$ . . 1.195.

$$d = \frac{8}{3} \times 0.082 + \frac{1}{7}(3.03) = 0.219\text{k.} +$$

$$0.423\text{ k.} = 0.642.$$

$$x = \frac{1.740}{77}(44 + 56 \times 0.6865) - 0.642 =$$

$$1.863 - 0.642 = 1.221 \text{ k.}$$

$$z = 0.97677 \times 1.221 = 1.192 \text{ k.}$$

$$\text{nitrogen} = 3.33 \times 1.192 = 3.969 \text{ k.,}$$

giving, per kilogram of product,

$$\begin{aligned} C\,O^2 &\ 1.195 \text{ k.} \\ C\,O &\ 1.740 \\ A\,z &\ 3.969 \end{aligned}$$

Weight of dry gas.. 6.904 k.

while complete analysis gives the following figures:

$$\begin{aligned} C\,O^2 &\ 1.195 \\ C\,O &\ 1.740 \\ A\,z &\ 3.965 \text{ difference } 0.004. \end{aligned}$$

6.900

We see that the agreement is as complete as possible. I will even say that *by chance* it is more complete than we had a right to expect, for the mode of analysis adopted by Bell is not perfectly exact. Though his results are the averages of several operations, it is impossible that a sample (*prise*), almost instantaneous, can really give the true composition of the gas of a blast furnace. A competent man, Ebelmen, referring to his own analysis at Seraing, said: "We must conclude that the analysis of the gas at the mouth does not represent the *mean* composition of the gaseous current." And yet Ebelmen regarded only the mean of the various gaseous currents at a given moment; while, in order to have an exact idea of the processes in a furnace, we must find not only the exact mean of all the gaseous currents at a given instant, but also the actual mean for a period of many hours. None of the methods of sampling the gas for experiment have done this up to this time. This leads me to the method of the following section.

(9)—MODE OF TAKING SAMPLES OF GAS, GIVING THE MEAN FOR SEVERAL HOURS.

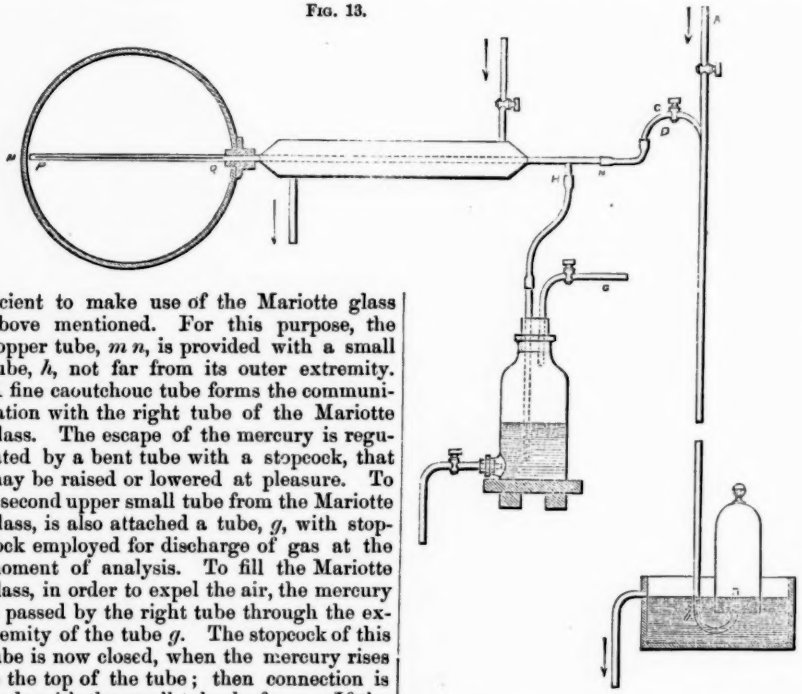
The system is due to the important researches of MM. Scheurer-Kestner and Ch. Meunier, with reference to the products of the combustion of oil. To have an exact mean, one draws, for several hours in a continuous manner, a certain total volume of gas delivered at the mouth along with the products of combustion, employing a Mariotte tube, filled with mercury, containing about 3 litres. The apparatus is shown in Fig. 13. A copper tube, $m\,n$, is inserted into the great iron conduit which receives the gas. This tube is 0.010 metre to 0.015 in diameter, and its length is nearly double the interior diameter of the conduit. The internal portion has along its entire length a slit, $p\,q$, about a demi-millimetre in breadth. This causes a uniform suction of the gas in all parts of the general current. The exterior half of the tube passes through a Liebig water refrigerator. The extreme end of the tube communicates by means of a caoutchouc coupling with the lead suction pipe, furnished with a cock to regulate the discharge of water, and with a lateral branch, $c\,d$, which is soldered to the verti-

cal tube *a b*, a little below the water-cock. It also carries a cock which, with the first, serves to regulate the discharge of gas. The end of this lateral branch, *c a*, is connected by a caoutchouc coupling with the copper tube, *m n*. Finally, the lower extremity of the pipe terminates in an iron tube filled with water, which permits the exact measurement of the gas by passing it under a glass jar.

In many cases, when the pressure is strong, the gas may be brought immediately into the lower tube, without using the current of water. But it seems better in any case to use the pipe, as it affords an easy way of regulating the discharge of gas. This may reach a velocity giving 4 to 5 litres per minute.

To obtain a certain fraction of this gas, say 2 or 3 litres in a few hours, it is sufficient to make use of the Mariotte glass above mentioned. For this purpose, the copper tube, *m n*, is provided with a small tube, *h*, not far from its outer extremity. A fine caoutchouc tube forms the communication with the right tube of the Mariotte glass. The escape of the mercury is regulated by a bent tube with a stopcock, that may be raised or lowered at pleasure. To a second upper small tube from the Mariotte glass, is also attached a tube, *g*, with stopcock employed for discharge of gas at the moment of analysis. To fill the Mariotte glass, in order to expel the air, the mercury is passed by the right tube through the extremity of the tube *g*. The stopcock of this tube is now closed, when the mercury rises to the top of the tube; then connection is made with the small tube *h* of *m n*. If the gas does not pass through the caoutchouc tube by its own pressure, the air is sucked out with the mouth, and connection is then made.

Fig. 13.



By this method samples may be obtained representing as exactly as possible the average of the gas escaping during several hours. If the tension is very different at the moment of charging, it is only necessary to draw off the gas during the intervals when the mouth is more or less closed.

As to the analysis of the gas thus collected, nothing is more simple, for it is only necessary to determine the ratio $\frac{CO^2}{CO}$. It is unnecessary to measure or to weigh the gas. The gas flows slowly from the Mariotte glass by the tube *g*. It is dried in U tubes with chloride of calcium or sulphuric acid. The carbonic acid is taken up by potash tubes; the oxide of carbon is burned by the oxide of copper; the water formed in the small quantity of hydrogen is kept back; and the carbonic acid derived from the oxide of carbon is determined by means of a second system of potash tubes. The analysis would be inexact only in the case when the gases contain appreciable quantities of carburetted hydrogen, which never occurs when coke is used.

A last precaution may be necessary in taking a sample of the gas, when there is much smoke, or the gases contain fine dust. The suction slit may then be more or less obstructed for a little time, as happened to Mr. Scheurer-Kestner in his experiments upon products charged with smoke. This may be remedied by a means employed by this skilful chemist. A kind of scraper made of a short plate of copper inserted in the tube and fastened to a movable rod keeps the slit clear.

After determining the ratio $\frac{CO^2}{CO}$ it is well to find the mean temperature of the gas, so as to calculate the sensible heat. When the minerals are not hydrated, the temperature of the gas may reach 400 deg. to 600 deg. C., so that the mercurial thermometer cannot be used. The thermo-electric pyrometer may be employed, or that of Lamy, which depends for action on the variable tensions of carbonic acid generated by the decomposition of carbonate of lime or magnesia.

(10)—DETERMINATION OF HEAT EXPENDED IN A BLAST FURNACE.

Suppose $\frac{CO^2}{CO}$ and the temperature of the gas at discharge to be known. Let us see how these elements serve to determine the action of the furnace. In the final analysis we must compare the heat received with the heat consumed. I have already shown how the heat of combustion may be found from ascertained values of CO^2 and CO. Later, I shall show how a separate estimate may be made of the heat produced in the zone of fusion and that generated in the zone of reduction. In both cases there must also be added to the generated heat that brought by the hot blast; easily done, if we know the temperature. It is the sum of the generated and imported heat, which I shall designate as the *received* heat.

The heat consumed consists of several parts:

1. The heat absorbed by reduction and fusion. It is a constant element for a given run (product), and varies little for different qualities.

2. The heat absorbed by the fusion of the slag, the decomposition of the limestone, the vaporization of the water, and the heat required for the decomposition of the water in the blast.

This second part is essentially variable, not only because of the very different quantities of limestone and of water, but also because of the variable composition of the slag, requiring different quantities of heat.

3. The sensible heat given out by the gas. This is also a variable element, but is always easy to calculate when the nature and temperature of the gas are known.

4. The heat lost by radiation, contact and the artificial refrigeration. Some attempts have been made to evaluate this loss; but generally, it can be found only by subtracting from the *received* heat the sum of the quantities consumed under the three preceding heads.

(11)—HEAT ABSORBED BY REDUCTION AND FUSION.

Suppose, as in (7), that the run is composed of 0.94 of iron, 0.03 of carbon, and 0.03 of silicium, etc. The heat absorbed in reduction is equal to that developed by 0.94 of iron in the state of peroxide, *plus* the heat furnished by the oxidation of the silicium, etc. The heat generated by the oxidation of the iron has been determined by several investigators.

By burning iron in oxygen, Dulong found that the heat produced per kilogram of oxygen is 4327 heat units.

Assuming that it comes from magnetic oxide, Fe^3O^4, we find, per kilogram of iron,

$$\left(\frac{4\times 8}{3\times 28}\right)\times 4527 = \frac{8}{21}\times 4327 = 1648 \text{ heat units};$$

or, by Welther's law, for the passage of Fe^3O^4 to Fe^2O^3, per kilogram of iron, yielding peroxide 1854 heat units; according to Andrews, cited by Bell, the heat generated by a kilogram of iron, yielding Fe^3O^4, is 1582 heat units, and for the peroxide 1780 heat units; according to Favre and Silbermann, for the transformation of a kilogram of iron into protoxide, 1352 heat units, giving for peroxide 2028 heat units.

The mean of these three results is 1887 heat units, the number which I shall assume for the heat absorbed in the reduction of peroxide of iron, per kilogram of product. But this number is only approximate. The experiments just cited do not agree in results; and we do not know that Welther's law is rigorously applicable in the transformations of protoxide and of magnetic oxide into peroxide. Besides, the heat disengaged or absorbed varies with the density and molecular condition of the products. The experiments of Despretz give a con-

siderably larger result, viz., that the combustion of iron generates 5325 heat units per kilogram of oxygen, corresponding to 2019 per kilogram of iron, passing to $Fe^3 O^4$, and to 2271, when the metal is changed into peroxide.

As to the heat furnished by the oxidation of the 0.03 of silicium, phosphorus, earthy parts, etc., this is more difficult to determine. exactly. According to the experiments of Troost and Hautefeuille the heat produced by the oxidation of silicium is 7830 heat units; and according to Andrews, that due to the oxidation of phosphorus is 5747 heat units. We do not know what is due to the earthy metals; but as the silicium is the chief constituent, we shall not be far from the truth in assuming 7000 as corresponding to these various elements. It is the more necessary to reduce the number, 7830 corresponding to pure silicium, because the combination of this element with iron is probably attended with a slight development of heat that cannot be estimated.

We may therefore assume that the reduction of the oxides will absorb, per kilogram of product,

For the iron, properly so-called	0.94 k.	×1887=	1774 h. u.
For other elements	0.03	×7000=	210
Total heat employed in reduction			1984

Of this amount about 1700 are consumed in the upper part of the furnace, and from 200 to 300 in the lower part, where the heat is higher.

To the heat of reduction must be added that of the product in the state of fusion. This consists of three parts—the heat absorbed in passing from the ordinary temperature to that of fusion, the heat necessary for liquefaction (latent heat of fusion), and that taken up in reaching the mean temperature of the furnace.

But in practice this difference is insignificant. The essential thing is to know the total heat of the run on leaving the furnace. It varies with the action of the furnace, and depends on the mean temperature of the hearth, or the degree of fusibility of the slag. If this is not easily fusible, as in the case of earthy protosilicates, the run will be hot, leaving the furnace at a higher temperature than if the slag was rich with manganese and alkalies, or if it consisted of bi-silicates of two or more bases. It is, then, not matter of surprise that determinations of the total quantity of heat in the runs, as found by several authorities, should not entirely agree.

Ordinary calorimeters are employed in finding the heat taken up when the run of the furnace is received in water.

Messrs. Minary and Résal, operating upon the product of the second fusion, ready to set, found 255 heat units. Rinman, under the same circumstances, found 261, 257, 256, and 252 heat units; of which 46 correspond to the latent heat of fusion.

Instead of 255, Minary and Résal found 292 heat units of total heat, in the case of hot grey iron (*fonte grise*) from a cupola furnace. But the run from blast furnaces is generally hotter than that from cupola furnaces. Rinman found 300 as a mean for a run from charcoal, with extremes of 270 and 311.

Boulanger and Dulait give

For forge pig, with coke	309 h. u.
For moulding iron	337 "

Kathaire gives

For white pig	280 h. u.
For foundry pig	330 "

Mr. Gilot gives 265 heat units for pig remelted in a cupola furnace, and according to the mean of two experiments at Bizy 337 heat units for grey iron of the first melting with charcoal.

Bell takes a mean of 330. This is the result which I think should be accepted for grey iron No. 3. But it is evident that experiments should be multiplied to determine at what point this number depends on the fusibility of the limestone and the special nature of the iron.

En resumé, the values of the heat absorbed by the reduction and the fusion may be taken, in the case of coke grey pig, No. 3, at

	1984 h. u.	for reduction.
	330 "	" fusion.
Total	2314 "	"

(To be continued.)

Messrs. W. F. Mosser & Co., of Allentown, find their business outgrowing the capacity of their foundry, and to meet the increasing demands made upon them are putting up an addition to their building of 37 ×39 ft. They are also erecting a machine shop 46×46 ft., which will be supplied with new and first-class machinery.

PRACTICE AND RESULTS OF IRRIGATION IN NORTHERN INDIA.*

From "The Engineer."

The object of the paper was to describe what had been done and what was now doing in that portion of Upper India where irrigation had been longest practised, and on the largest scale. The conditions which created a demand for artificial irrigation were exhibited by a map showing the average rainfall over the surface of British India, distinguishing the rainfall of the north-east monsoon and of the south-west monsoon. The tract of country under consideration was included between the Himalaya range on the north, the river Brahmaputra on the east, and the rivers which merged into the Indus on the west. The principal geographical features of the region were the plains drained by the Ganges and the Indus and the intervening table land of Central India, comprising a country four times as large as France in area as well as in population. The plains of the Ganges and of the Indus rose gradually from the level of the sea to an elevation of 1,000 ft. to 1,100 ft., where those rivers debouched from the mountains, and the highest general level of the central table land was about 2,000 ft. The distribution of the rainfall in India was then noticed. It was very large during the south-west monsoon along the range of the western ghats, much less in the interior, and it rapidly decreased towards the mouth of the Indus; but it was again larger on the table lands bordering the valleys of the Nerbudda and the Taptee. At the southern point of India and in Ceylon the south-west monsoon brought but little rain, which, however, increased up the eastern coast of the peninsula, and on the east of the Bay of Bengal there was an abundant fall, which extended over the country between the sea and the Himalaya; thence, in the plains of the Ganges, the rain constantly diminished as the distance from the sea and from the Himalaya increased. These varying conditions of moisture involved different agricultural conditions, which were influenced by diversities of soil and temperature. The temperature ranged from tropical in the south, with an approximately uniform heat, to semi-temperate in the north, where the summer and winter were sharply defined.

The North-Western Provinces, exclusive of the Benares division, where there were no State works of irrigation, might be described as consisting of three zones:—

(1.) The sub-Himalayan tract, north of the river Ranegunga, which was copiously watered by the rainfall on the mountains and by numerous small rivers flowing out of them. Most of these rivers dried up after the termination of the rainy season; but on a great part of the length of this tract a deposit of sand and boulders, forming a continuous belt fifteen miles wide, created a vast filter bed, which, being bordered on the down-hill side by a band of clay, became a covered reservoir. The natural pressure, augmented by the rapid slope, across which the filter bed laid, forced water under the clay, and produced a line of springs on the other side of the clay band, which fed numerous small streams and refreshed the country. The local name of the belt of boulder was "Bhabur," and of the tract which it watered by filtration "Terai."

(2.) The plains, being the area included between the Ranegunga and the Jumna rivers, and including the Muttra and the Agra districts on the right of the Jumna. This tract has a loamy upper soil varying from sand in some parts to light clays in others. But fine sand was generally found at no great depth. In this tract the drainage ran from north-west to south-east, parallel to the Ganges and the Jumna, which rivers embraced nearly the whole area.

(3.) The Province of Bundelcund, which sloped from the high table lands of Central India northwards towards the Jumna. The lands bordering the rivers were dry and stony, and higher than the intervening basins, which consisted generally of rich black cotton soil. There had been a great upheaval of the region near the foot of the table land, and trap and granite rocks cropped out freely, forming isolated hills of fantastic shapes.

The climate of the North-Western Provinces was exceedingly dry, and hot westerly gales prevailed in April, May, and June, during which months vegetation of un-

* A paper read before the British Institution of Civil Engineers, by Col. W. H. Gaekered, R. E.

watered plants was apparently suspended except in the case of the melon tribe. The rain clouds of the south-west monsoon seemed to travel up the Ganges, and they reached the North-Western Provinces about a fortnight after rain had fallen at Calcutta, when the season of agriculture commenced. The agricultural operations, it was observed, were of the most primitive description, and the crops were liable to fail if the fall of rain was not distributed over a sufficient number of days, or was otherwise deficient. The uncertain crops of the rainy season were Indian corn and millet of various kinds, which formed the staple food of the agricultural laboring classes.

The rainfall in Hindostan of the winter or north-east monsoon was everywhere less than in the summer. It was most felt on the eastern coast, from Madras downwards, and in Ceylon was very copious. On the western coast the only considerable winter rain was between Cannamore and Vingorla. As in the south-western monsoon, the rainfall of the north-east monsoon diminished in the valley of the Ganges as the distance increased from the sea, and became very light in the North-Western Provinces and the Punjab, where it was due at Christmas. If the winter rain was favorable the barley and wheat had a fair chance, but on unirrigated lands the spring crops of cereals were always uncertain. In the Bundelcund zone barley and wheat were scarcely ever sown, on account of the exceeding dryness.

The plains had an average annual rainfall of 26.6 in.—enough for agricultural needs; but as the greater part fell, perhaps, in a fortnight, and there was no rain from September to July, except the Christmas showers, the ordinary crops of the country often failed, and the richer crops were entirely dependent on artificial irrigation. In the sub-Himalayan zone, which had a rainfall of 48.7 in., rice was successfully produced, without artificial irrigation, in about two years out of three; sugar was less certain under the same condition. In Bundelcund the average rainfall, 33.7 in., sufficed for the ordinary monsoon crops, but it was especially fickle, and scarcity was in consequence very common in that country.

The people of the North-Western Provinces had practised sinking wells for irrigation from the earliest periods. The depth at which water was found in the plains varied from 10 ft. to 50 ft. below the surface. At the lesser depth a little pit supplied as much water as could be lifted in a day in a jar attached to a light balance beam worked by men. Two men could keep a plot of an acre watered, but the demand on labor prevented its employment on a large scale. Pits of this description fell in during the rainy season, and had to be annually renewed at the cost of the tenant. Deeper wells, lined with brushwood cylinders, and worked by bullock power, cost from £5 to £18 apiece, and employed six men and three pair of bullocks every day to keep five acres watered. The duration of such wells varied, according to the soil, generally between two and ten years, and in some favored tracts could be constructed without lining. A serious objection to the majority of wells was that they contained surface water only, and did not touch the springs, and if overdrawn they fell in. As a rule the springs could only be reached by wells lined with brickwork, costing from £15 to £30 apiece, which cost was almost prohibitory to their employment for irrigation. Where water was plentiful they paid best when made of sufficiently large diameter to allow three or four pairs of bullocks to work at once, in which case they commanded twenty acres of land, and cost up to £80 and £100 apiece.

In the sub-Himalayan zone wells had not been much used for irrigation; the people had instead dammed the rivers and led off from the dams irrigation channels to the fields; but the consequent stoppage of outfall had waterlogged the country, and given rise to malaria. A bill was now before the Legislative Council of India for the removal of the whole of these dams, on the Government making proper compensation either in water supply from other sources or in money. In the third, or Bundelcund zone, no wells could be sunk for purposes of irrigation, because of the depth of the water from the surface, the poverty of the community, and the scanty population. The amount of land irrigated from some lakes had not as yet exceeded 1,300 acres. Although individually diligent in their own concerns, the natives of Northern India were wanting both in the means and in the mutual confidence requisite for combinations in works of general advantage; and generally, improvements, unless proposed and carried out by the officers of the Government, were not done at all.

Extracts were then given from the official account of the famine of 1868–69, describ-

ing the desolation in districts unprovided with canals, and the security of those that were irrigated.

The scheme projected for turning all available waters to the greatest advantage was next detailed. The characteristics of the rivers Ganges and Jumna, which included between them the larger part of the zone of "plains," were identical. Both rose in eternal snows, and both received large affluents before leaving the mountains. The drainage area of the Ganges was 11,200 square miles, that of the Jumna 7,800 square miles. The flow of water in the greatest floods was respectively 230,000 and 160,000 cubic feet per second, and when these rivers were at their lowest, from the middle of January to the end of March, the flow was reduced to 4,000 cubic feet and 2,000 cubic feet. Unfortunately the period of lowest supply was that of greatest demand. The rivers left the Himalaya on boulder beds, sloping 8 ft. to 10 ft. in a mile, which after a few miles were replaced by fine sand, wherein the course of the rivers was constantly varying. Beyond the end of the boulder formation the surface of the rivers was generally about 40 ft. below the adjacent country.

The head works of the Ganges and the Jumna canals had been fixed on the boulder portion of the river beds on account of its stability, and for facilities for leading and regulating the supply of water. All the water in the rivers in January was required, to obtain which dams were constructed across the perennial streams of the rivers, and at times the whole of the visible water was turned into the canals. Temporary dams of crib-work, boulders, and shingle, were found to be the most suitable for diverting the water, whilst masonry structures were preferred for the regulation of supply channels. The Ganges Canal was perhaps the largest work of the kind in the world. Its full capacity was 6,500 cubic feet of water a second. The width of bed on the Solani Aqueduct, 18 miles from the head, was 164 ft., and the depth 10 ft. The main channel was 348 miles in length, and it was navigable throughout; the branches were 306 miles in aggregate length, and the distributaries 3,071 miles. A carriage road was kept up on all main and branch canals, and the banks were planted with timber trees. The flow of water per second in 1870—71 was 4,300 cubic feet, and 767,000 acres were watered in 5,061 villages. Irrigation commenced 22 miles below the headworks, and was diffused over an area 320 miles long by about 50 wide. The sub-Himalayan drainage, which the canal crossed, was passed partly into, partly over, and partly under the canal. The works in the upper part were chiefly constructed on block foundations, perforated with wells, by means of which they were sunk in running sand to a hard stratum. The Solani Aqueduct, spanning a valley 2½ miles in width; its foundations were supported by the pressure and friction of wet sand, and no subsidence had occurred. The slope of the country in the upper part of the canal was much more rapid than that given to the canal beds, a difficulty which had been overcome by masonry ogee falls; in place of these, vertical weirs with long crests were being built on new canals. The difficulty of the conditions under which the Ganges Canal works were commenced was detailed, and the functions of the canal officers. The earning of a cubic foot of water on the Ganges Canal, in 1870–71, was £44 per annum; on the Eastern Jumna, £59.

The net income of all the canals in the North-Western Provinces, in 1870–71, after the payment of working expenses, was £182,437, being 6.64 per cent. on the capital cost of £2,714,631. Measures were now in progress for reducing the rapidity of the current of the Ganges Canal for navigation purposes; and a commencement had been made in leasing the water-power to persons competent to utilize it.

As there was no water in the Ganges Canal available for extensions, it had been determined to construct a weir across the Ganges at Rajghat, for a Lower Ganges Canal, with a capacity equal to that of the Upper Canal, on an estimate of £1,825,000. The combined system would probably be completed for £5,000,000, and return 13 per cent. The weir across the Ganges at Rajghat would be founded in running sand.

The Agra Canal had been projected for the irrigation of the Muttra and Agra districts, on the right bank of the Jumna, below Delhi. A weir 2,428 ft. long had been built across the Jumna, at a point where a spur of quartz from the Aravali range abutted upon the river. The work had no foundations. It consisted of two parallel masonry walls, 2,428 ft. long, running from end to end of the weir, of which the footings rested on the fine sand of the river bed at low-water

surface level. Between these walls, which were 26 ft. apart, stone was packed, and a slope of stone was constructed, up stream with a base of 40 ft., and down stream with a base of 200 ft. Scouring sluices were constructed on one flank of the weir, to keep a clear channel in front of the canal head. This weir, when partially constructed, had satisfactorily withstood the greatest known flood on the Jumna. The Agra Canal had a maximum capacity of 2,000 cubic ft. of water per second, and was designed to irrigate 350,000 acres. For the benefit of the plains and zone east of the river Ganges, an Eastern Ganges Canal was about to be constructed, taken off at the bottom of the boulder formation. This would water 450,000 acres, equal to 35 per cent. of the area of the districts commanded.

In the Bundelcund zone, owing to the granite and trap formations, the rainfall was carried off by the rivers with great rapidity, leaving the river beds almost dry soon after the rain had ceased. The channel of the river Betwa was 1,450 ft. wide, and 61 ft. deep near the town of Jhansi. This was often filled in July and August, the flow of water being 700,000 cubic ft. per second; yet, in January, the flow was reduced to 50 cubic ft., which passed through a notch 6 ft. wide. It was intended to build a weir across the river Betwa 26 ft. high. The Betwa Canal would then water 120,000 acres in the Jaloun and Humeerpore districts. The estimated cost was £170,000, and the anticipated return from water-rate 10 per cent. Other weirs were projected across the rivers Dussan and Keyn, estimated to cost £124,000 and £130,000 respectively, and to return 11 per cent. on the outlay; the weirs would stand on granite sites. Lastly, 15 lakes in Bundelcund would be made available to water 22,000 acres and to return £2,500 a year on a capital outlay of £8,200. By these means 700,000 acres would be annually watered in Bundelcund and Jhansi, an area sufficient to insure the province against famine, and, it was hoped, to restore it to its pristine fertility.

The financial results were then explained. At the end of the year 1871 upwards of a million acres were irrigated from existing works, which afforded a net return of £182,500. The capital expended had been £2,747,000, and the net profit on the whole was 6.64 per cent. When fully completed the cost of the undertaking would amount to about £7,500,000, with a return of 12 per cent. on the capital when the canals were fully developed.

A large system of canals had been projected for the irrigation of the province of Oude, from the river Sardah, and would extend to some part of the Benares division.

In the Punjab, at the foot of the Himalaya, there was a zone of rainfall of 40 in. a year, bounded on the south by a belt where the rainfall was 16 in.; the remaining country to the south was almost rainless. The principal canal in operation was the Western Jumna, an old Mohammedan work. It had paid nearly £2,000,000 clear profit, after repaying capital. The Baree Doab Canal, taken from the river Ravee, was constructed on the model of the Ganges Canal, and was gradually making way.

There were profitable inundation canals on the Indus, the Chenab, and the Sutlej. The Sirhind Canal, now under construction, would cost about £2,000,000, and irrigate a country where rain was very scarce. It was calculated to pay about 9 per cent.

It was observed that whilst the characteristics of irrigation in the North-Western Provinces, Oude and the Punjab, were much alike, they differed largely from the conditions current in Madras. In Northern India irrigation was carried over the whole country; crops were watered both in winter and in summer, and irrigation afforded the greatest benefit in the winter, where there was little or no rain; but in Madras canal irrigation was only effected during the rainy season when rivers were full, and was confined to the deltas at the mouths of the great rivers.

In conclusion, it was stated that about 250 engineers, of and above the rank of assistant-engineers, were employed, under the Indian Department of Irrigation, in developing the advancement and prosperity of the country.

The Alliance Rolling Mill Company are working full force, and during one month turned out 2,200 tons of rails. They have, during a single month, received 480 cars of materials, and shipped 400 cars of their products. During one week they shipped to the Pennsylvania Company 1.870 tons of rails. The pay-roll of the company at the Alliance mill alone alone is $18,000 per month.

BUILDING-STONES.

From the "Boston Daily Advertiser."

We find in the columns of an Eastern daily ("Boston Advertiser") an account of some recent experiments on the artificial building stones now prominently before the public. Although no test that can readily be applied can be satisfactorily substituted for the *weathering* to which the building materials of our cities are subjected, such tests as are described by the writer yield results of undoubted value. We quote: Effort has been made to test fairly the artificial stones now prominently before the public, and to compare them with the natural stones in general use. The result in his mind has been a full conviction that artificial stone will, ere long, be extensively used, and, to a considerable extent, take the place of natural stone. The artificial stones examined have been the American Building Block, made by the Middlesex Stone Brick Company, the Frear stone made by the Massachusetts Frear Artificial Stone Company, the Union (Sorel) stone made by the Union Stone Company, and the Coignet stone made by the New York and Long Island Coignet Stone Company. A preliminary remark may be of advantage. Many object to artificial stone because it is artificial. A sufficient answer is, that very many of the most valuable materials of industry are artificial; *i. e.*, they are composed of native elements brought into new relations and forms by the labor of man, guided by knowledge, which is the result of accident or study. Among these are iron, in the forms in which it is ordinarily used, steel, glass, brick, leather, vulcanized india-rubber, etc., a list which might be indefinitely extended. Why, then, may not man, having the lime, alumina and silica, and other elements which enter into the composition of so many of the best natural stones, combine them in accordance with the laws of chemical affinity, and make a stone which shall have all the valuable qualities of a natural stone? This question has peculiar force when we think of that old artificial stone of Rome, which remains to this day as hard as flint, while the natural stones, of which it formed the mortar-bond, have in many instances been disintegrated and decayed.

The points as to which a comparison is desirable are:—

1. STRENGTH.

Most of the stones of either class, as well as hard bricks, have sufficient strength for any probable need. Buildings of brick have fallen, owing to the poor quality of the brick or of the mortar. The crushing strength of weak, red brick is from 500 to 800 lbs. to the square inch of surface; that of the best quality is about 4,400 lbs. Buildings of so-called artificial stone have also in some instances fallen. The case of the Howard University, built of the American building block, is well known. Samples taken from the falling wall had a crushing strength of only 173 lbs. for samples four months old to 443 lbs. for those twelve months old, much less than that of soft brick, while the strength of the Union (Sorel) stone and of the Coignet stone (both of them artificial) is from 5,000 to 10,000 lbs. to the square inch, that of the best marble being 8,950 lbs., and of Quincy granite, 15,300 lbs., and of brown-stone, from 3,000 to 5,500 lbs.

2. PERMANENCY.

On this point we present an extract from a paper by J. H. Owens, M. A., a distinguished English architect, who, speaking of the use for building purposes of Portland cement concrete (which is really an artificial stone, crude indeed and roughly made), says: "Every other material used in building, except the hard granites and the most compact limestones, depreciate with time and exposure, and require an initial excess of material to be used, whereas Portland cement concrete is permanent and durable under all circumstances, and increases rapidly and enormously in strength, and continues to increase, but in a continually diminishing ratio, for as long as observations have, up to the present time, been made upon it." The Coignet stone, which, like the Portland cement concrete, is a hydrosilicate of lime and alumina, but far superior in the density and homogeneousness of its structure, resulting from the vastly superior conditions and methods of its manufacture, possesses the same characteristic, specimens more than a year old having shown, under hydrostatic pressure, a crushing strength of over 12,000 lbs.

3. RESISTANCE OF FROST.

This depends very much on the structure of the stone. Granite and marble are granular in structure, while brown-stone is laminated and liable, from the natural cleavage, to scale off, in consequence of alternate thawing and freezing. Artificial stone is frequently so made as to be liable to the same difficulty, a liability entirely obviated in the Coignet stone by the method of aggregating the particles patented by M. Coignet, producing a perfectly homogeneous stone, resembling in its structure the most compact marble, and without tendency to cleave in any particular direction. It is also, according to the testimony of Dr. Walz, analytical chemist of New York, who subjected specimens of it to very severe tests, "practically impervious to water."

4. RESISTANCE TO HIGH DEGREES OF HEAT AND ADAPTATION TO THE CONSTRUCTION OF FIRE-PROOF BUILDINGS.

In reference to this point the writer subjected samples of various natural and artificial stones to the following tests. Pieces of the different kinds were heated to redness and then allowed to gradually cool. Other pieces of each kind were heated to redness and immediately plunged into cold water. Quincy granite was in both cases disintegrated. White marble was much weakened in the first test, so as to be easily broken by the fingers; in the second it was rendered quite friable. Soapstone was, in either case, affected but very slightly if at all. Brown-stone (good specimens from Portland, Ct.) in both cases was disintegrated quite as much as the granite. Brown-stone from Seneca, Md. (the most compact brown-stone ever examined by the writer), in both tests appeared to be uninjured. Nova Scotia free-stone was somewhat weakened, but endured both tests better than the other natural stones, except soapstone and Seneca brown-stone. Of the artificial stones, the American building block (samples from a block made by the Middlesex Stone Brick Company, and more than two years old) was in both tests even more completely disintegrated than the granite. Frear stone (made in Worcester, and about eighteen months old) was affected rather more than the marble, becoming very brittle. The Union (Sorel) stone (two years old) was in the first test disintegrated as much as the granite; in the second test, when the heated piece was plunged into the water, a chemical change was immediately produced, indicated by a violent effervescence, and the stone crumbled into small grains. The Coignet stone endured both tests equally well with the soapstone and the Seneca brown-stone, not appearing to lose any of its strength. As to the result in the last-named stone we quote again from Mr. Owens, who says of the Portland cement concrete (of which, as we have said, the Coignet stone is a cognate) that "it is the only fire-proof building material." Another sample of the Coignet stone, of inferior quality and coarser texture, was subjected to the same tests, with equal satisfactory results.

6. ADAPTATION TO ARCHITECTURAL ORNAMENTATION.

In this respect artificial stone has greatly the advantage of natural stone, as all forms of ornament from the boldest to the most delicate, the plainest and the most elaborate, can be rendered in artificial stone at a much less price, the ratio of comparative cheapness increasing with the degree of ornamentation.

The Coignet stone is the result of experiments, conducted through several years, by Mons. F. Coignet, a civil engineer of Paris, who perfected and patented his process in 1856. In France there was at first great prejudice against it, and it was used very cautiously and in minor structures, but, after years of experience of its value, it received the unqualified approval of the architects and engineers of Paris, and the official sanction of the French Government, which has adopted it for many very expensive works and on an immense scale. General Q. A. Gillmore, of the United States Engineers, was sent to France to examine officially structures of the Coignet stone and to ascertain its adaptability to Government works. In his report, made to the War Department and published by its authority, he says: "Many interesting applications of this material were examined, of which it is not necessary to make any special mention except that in combined stability, strength, beauty and cheapness, they far surpass the best results that could have been achieved by the use of any other materials, whether stone, brick, or wood. For warehouses, churches, and large buildings of every description, for foundations, abutments and massive walls of all kinds, for side walls,

platforms and flagging, and for many other minor purposes, Coignet stone possesses not only great comparative cheapness, but all the essential merits of brick and stone, with respect to strength, hardness and durability, while for many purposes, within the province of the architect and engineer, it possesses advantages peculiar to itself, and not equally shared by other materials." This process has been in use for about three years in this country. The New York and Long Island Coignet Stone Company, having a large capital, extensive buildings and yards, and ample machinery and other facilities, are doing a very large and profitable business in New York city and Brooklyn. Among the leading architects of New York who recommend its use are Messrs. Renwick & Sands, Olmstead & Vaux, C. C. Haight and R. Lockwood. The last-named gentleman says of it: "I have no hesitation in saying that it is a most valuable invention and addition to our building operations—one that will meet a great architectural want, that of affording the means of the highest ornamentation, joined to great solidity and strength, at a cost far below any other enduring materials."

HEAVY GUNS AT SEA.

From "The Engineer."

The papers read at the Royal United Service Institution are generally so sound and carefully prepared, that we feel some regret in noticing one which affords a complete exception to the rule. The paper to which we allude, "On the Bessemer Saloon as applied to Training Guns at Sea," was read on Monday night by Lieut.-Col. Strange. The author evidently felt that an apology was due to the members of the Institution for the character of the matter which he supplied; and while studiously avoiding details he protected himself still further from adverse criticism by stating very plainly that the propositions he put forward were intended only to elicit discussion; and to do him justice, he afforded no grounds for assuming that he warmly advocated them. How, under such circumstances, he came to write the paper at all we shall not pretend to say. Briefly stated, its purport went to show that the system of mounting cabins or saloons on board ship, patented by Mr. Bessemer, might be applied with advantage to the working of heavy guns at sea. But this proposal would not in itself have supplied sufficient matter, and Col. Strange, therefore, went on to discuss the whole question of armor or no armor, expressing his opinion that armor was worse than useless, principally because Mr. Bessemer could supply a gun which would throw a 5-ton projectile, with a charge of 400 lbs. of powder, such guns of course being sufficiently powerful to set all armor at defiance; and he went on to add that it would be proper to build a fleet of gunboats, each carrying one of Mr. Bessemer's great guns mounted on one of Mr. Bessemer's steady platforms. Our naval and military friends will not be surprised to hear that during the ensuing discussion these propositions were completely demolished by Captain Selwyn and Commander Dawson, and thus the high character of the Institution was fairly maintained after all.

We believe we only do Mr. Bessemer justice when we assert that no one is better aware than he is himself of the unsuitability of his steady saloon principle for use in mounting heavy guns at sea. In fact, it could not well be otherwise, for no one has had so much experience with his invention, or has given the subject so much thought. It is the misfortune of inventors that the moment they apply any well-known principle to a particular purpose in a way not before generally recognized as being possible, they are liable to be beset by a host of friends ready to suggest a multitude of other applications of the same principle, without the slightest regard to the fact that, however well adapted a given mechanical combination may be to a required specific purpose, it by no means follows that it is equally applicable to every other purpose which possesses some similarity, more or less remote, to the first. Mr. Bessemer appears to be in this predicament, and to find it no easy matter to teach his friends moderation in their zeal. We once knew an engineer of some talent who invented a very neat donkey pump. He invited many to see this pump at work. Generally speaking, those who saw it became enthusiastic as to its merits, but as a rule, they all

wound up by saying, "Exactly the thing for a steam fire engine." Now the inventor was well aware that, however suitable for feeding boilers, it was not suitable at all for a steam fire engine, so the statements of his friends greatly disgusted him. At last he asked a man on whose judgment he placed much value, to go and see the pump in operation, and give him his opinion of it. This gentleman went into every question of cost of manufacture, etc., and reported unfavorably. This the inventor could have got over; but the reporter, with the amiable intention of taking away the sting, added a species of postscript to this effect: "Although the invention could never be made commercially successful as a donkey engine, it could be applied, I think, with much advantage as a steam fire engine." This was the last straw, and the inventor abandoned his patents and turned his attention at once to something else. Mr. Bessemer is, we fear, in a fair way to a similar fate. Already a host of applications of his system are talked about, and there is a prospect that the Bessemer saloon will be swamped by the sea of "suggestions" which rolls round it.

Of all these, none is more forced or artificial than that embodied in Col. Strange's paper. Either very heavy guns must be mounted on ships of great size, or in gunboats, that is to say, vessels of 600 tons or so; for it is difficult to see of what use a 35-ton gun could be in a much smaller craft, unless, indeed, the craft never was expected to leave the sheltered waters of a harbor. If the gun is to be mounted on a ship, it must be hung so high that when the ship rolls, say, to leeward, the gun can be fired to windward without sending the projectile through the deck. If this be so, the height of the armor protecting the gun must be increased in proportion, and the portholes most also be vertically augmented in area until the armor would become almost useless. Again, it is impossible to build a man-of-war which will not pitch. It appears, therefore, that not more than one gun could be mounted on board a ship, however large, because the further we get from the centre, or transverse midship line, the greater will the pitching and ascending motion become, and the guns will be moved up and dropped down vertically through very considerable distances whenever there is any swell on. The great difficulty encountered in working heavy guns in a sea has lain, not in taking aim, but in controlling the motion of the gun in a sea; but Captain Scott has disposed of this difficulty in a way which really leaves Mr. Bessemer no room for improvement; and we believe that all our nautical readers will agree with us that the only advantage which mounting guns on the Bessemer saloon system would confer would be dearly purchased at the cost of the necessary limitation in the number of guns carried, and the great elevation at which they should be fought if any advantage was to be gained from the new system of mounting.

If the scheme be unlikely to succeed in the case of ships of war of 6,000 or 7,000 tons burden, it is still more unlikely to prove applicable to the case of what has been termed a "Hornet fleet," that is to say, a multitude of little gun boats, each mounting one heavy gun, and relying on their small dimensions for impunity from an enemy's fire. If the sea were smooth when an action was progressing, these cockle-shells would be steady enough not to need a Bessemer platform. If the sea were rough, they probably could not take any part whatever in a naval engagement; and if they could, no possible device would steady the gun; the little craft would toss and pitch in a way utterly to baffle human ingenuity. In one word, before the Bessemer saloon system can be applied successfully in practice, the construction of our ships of war must be completely altered; so that the gun may be fought without any protection from armor in very large ships, and at a great height above the deck; and we venture to think that this arrangement is not likely soon to be adopted. Nothing will give us more pleasure than to see Mr. Bessemer's invention, as applied to Channel steamers, fully and fairly tried, and to confess, when it has proved successful, that we have been mistaken concerning its merits as a means of preventing sea-sickness. But we hold that it would be simply a waste of the public funds to spend money, as suggested by Colonel Strange, in experimenting with the same system as a means of mounting heavy guns. Experiment can, in this direction, teach us nothing which we do not already know perfectly well, and therefore experiment cannot add to our knowledge. If the laws determining the occurrence of sea-sickness or immunity from nausea were as well defined as the facts concerning the working of heavy guns at

sea, it would be waste of money to fit a Bessemer saloon to a Channel steamer. There is a possibility, however, that the saloon will give comfort to many persons who would otherwise be wretched; but it is certain that the system cannot be applied to the working of heavy guns without introducing difficulties and objections which no inventor could overcome unless he were left at liberty to dictate the conditions under which every future naval battle should be fought.

REPORTS OF ENGINEERS' SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—A regular meeting of this Society was held at its rooms, in New York, January 15th, 1873.

A paper by Casimir Constable, C. E., of New York, "On Retaining Walls: An Attempt to reconcile Theory with Experiment," illustrated by a model, was read.

A retaining wall is stable when the moment of its weight about the point of rotation exceeds the moment of a certain triangular prism of material back of the wall about the same point, the intersection of the line of rupture of the wall, and the resultant thrust of the prism.

Many formulæ and tables for retaining walls are presented for use without a factor of safety, since walls proportioned therewith, well built, and carefully "back filled," have been permanent.

Experiments made on a small scale, in which the theoretic conditions were more nearly fulfilled than in practice, show that such walls are more than stable, and point out the reason why.

The problem having been thus solved, a factor of safety may be introduced in the formula, which will allow for shocks, irregular workmanship, and uncertain material.

The problem may be considered under these several heads: the angle of rupture, the height of the prism of rupture, and the direction and point of application of the pressure of the prism.

Angle of Rupture.—This was first supposed to be the angle of repose with the vertical; the thrust was assumed to be horizontal, and at $\frac{2}{3}$ the height of the wall.

Belidor assumed the angle at 45 deg., and that the earth moved in layers parallel to the line of rupture.

Coulomb first considered the slope of earth, with the attendant physical conditions; his theory as amplified by M. de Prony, is discussed by M. Gauthey, who gives a clear analysis of the angle of rupture.

Supposing the resistance of cohesion is proportional to the surface of rupture, and the friction to the normal pressure,—the pressure against a retaining wall is that of the prism of earth, which would at once fall if the wall were removed. The inclination of the plane of separation of this prism will vary with the cohesion and friction of different earths. If a series of planes be conceived, less inclined than that of repose, and originating from the same point, one of them will have such a position that the separating prism will have need of a greater opposing force to its sliding motion than any other.

Upon this hypothesis it is proved the prism of greatest pressure is given by the plane which bisects the angle of repose, and that

$$P = \tfrac{1}{2}\, W,\ h^2\ \tan^2\ \frac{i}{2}$$

in which P = the horizontal force which sustains the prism, w, the weight per cubic foot,—h the height, and i the angle of repose of the prism.

Lieut. Hope found, with layers of colored sand, the average angle of rupture to be 24 deg., and of repose 54 deg. This small difference in practice from theory is probably due to the cohesion of particles, an element which, from lack of sufficient data, is generally disregarded.

Height of Prism of Rupture.—From the first it has been assumed that the wall turned over as a solid mass about the bed joint at its base. In practice it is not so; the line of rupture is a stepped line, in or near the natural slope, and leaving a part of the wall undisturbed.

For experiment, a box 16 in. high and wide and 24 in. long, with glass sides, was made. A miniature wall of pine blocks or "bricks" 1 in. sq., 2 in. and 3 in. long, with a bank of oats or peas instead of earth, in eight trials turned over as stated. When the wall began to move, the face bulged out, the centre of the curve being at about one-half the height, and would continue thus until started forward by a jar. This, due to cohesion of the backing, doubtless adds materially to the stability of walls of long standing, which, it is often noticed, stand, although bulging outward. (This, and subsequent statements, were illustrated by experiment.)

A solid wall with a joint at the place of separation was more stable than one of "bricks," for although each began to move at the same time, the first did not continue to give way, and required to be continually started.

Navies seems first to have noticed that walls rupture in this manner. It is reasonable that the prism of pressure should start at a point above the foot of the wall, for by rotation of the wall about the outer point in the base, the lowermost portion of the backing must be lifted.

Experiments made in the case of surcharged walls, gave heights agreeing very closely with those calculated upon this basis, while assuming the prism of pressure to start from the foot of the wall, would give a height far below that sustained.

Direction of Thrust.—If the weight of prism of greatest pressure be resolved into two components, one normal to the slope of rupture, and the other to the back of the wall, the first will resist by its friction the tendency to slip along the slope; the second is expressed by the formula given, and may be resolved into two other components—one inclined, the actual thrust against the wall—and one vertical, to overcome the friction along the wall. This latter, from the indefinite knowledge of the value of the coefficient, is generally neglected. The point of application of thrust, at first assumed to be $\frac{1}{3}$ the height of the prism of pressure, which gave too great thickness to the wall, has been shown by Rankine and others to be at $\frac{1}{3}$ the height from the foot. The height of the prism of pressure will

be from .70 to .75 of height of wall. The conditions of the problem are now determined, from which follow these formulæ:—

$$\frac{t}{p} = -\left(n + \frac{n_1}{2}\right) \pm \sqrt{\frac{2\tan^2\frac{d}{2}}{7w}\left(w_1 + \frac{8p}{3}\right) + \frac{n^2}{3} - \frac{n^2}{12}}$$

in which t = thickness at top of wall: p = any weight per square foot of surface distributed over the bank; n = batter per foot in height of outside, and n_1 = the same of inside of wall; d = angle of repose; w = equal weight per cubic foot of masonry, and w_1 = same of earth. If n and $n_1 = 0$

$$\frac{t}{p} = \sqrt{w + \frac{8p}{3}} \tan\frac{\alpha}{2}$$

and if $p = 0$

$$\frac{t}{p} = .53 \tan\frac{\alpha}{2}\sqrt{\frac{w_1}{w}}$$

This would have been .57 instead of 53, in case the prism was assumed to start from the foot of wall.

Rankine's theory of earth pressures makes the thrust parallel to the surface of the bank; accepting this and these results—

$$\frac{t}{p} = .57 \sin\frac{\alpha}{2}\sqrt{\frac{w_1}{2}}$$

differing from the usual formula in substituting

$$\sin\frac{\alpha}{2} \text{ for } \tan\frac{\alpha}{2}.$$

This gave results very close to those obtained by experiment, and considerably less than those from the formula last given; which, perhaps, accounts for the general omission to employ a factor of safety.

Transformation of Profiles.—Vauban's rule—that a rectangular wall may be transformed into one of equal stability, with a batter on the face, having the same thickness at $\frac{1}{3}$ the height, is true within $\frac{1}{12}\frac{1}{10}$ when the batter exceeds $\frac{1}{n}$.

Now it is usual to give a less batter, and by taking the common thickness at $\frac{1}{10}$ the height, the error is inconsiderable. [This was proved by experiment.]

In a surcharged wall, if the surcharge starts from the back of the wall

$$\frac{t}{h} = .38 \cos d \sqrt{\frac{w_1}{w}}$$

and experiment verifies this.

Uniformly, when the experimental wall first gave way, the filling did not revolve, as stated by some writers, but settled suddenly and then rested until another shock started it again. This seems to show the advisability of stepping the back of walls.

Much depends upon the manner in which the work is done after the profile has been fixed; inattention to the details of construction may jeopardize the safety of a structure well proportioned.

For several years pains have been taken to collect data of walls in existence, with a view to establish a co-efficient, safe under ordinary conditions, and which may be modified by the engineer to suit particular cases.

DISCUSSION.

Mr. J. Dutton Steele gave a practical rule, verified by his experience, for surcharged walls of dry masonry, less than 18 ft. high,—namely, a width of 3 ft. at top, a batter of $\frac{1}{3}$ outside, and none inside. In one case, for a mortared wall 18 ft. high, he reduced the thickness at the top to $2\frac{1}{2}$ ft., and gave a batter to both sides. Engineers, who from lack of room have been compelled to lay walls upon narrowed or stepped foundations, will be pleased to know, from Mr. Constable's experiments, that such conform to theory, and are safe in practice.

Mr. Collingwood inquired whether it was not best to step the back of a wall, rather than give it a batter.

Mr. Constable said it was more a matter of practice than of theory; by thus stepping a wall, the back filling upon settlement did not act as a wedge.

Mr. Steele said that generally now, the back of a wall is not stepped as formerly, but made vertical; often in railway practice it is counter-sloped or under-cut, and the stability thereby increased. The back should have a "frost' batter at top, where the earth is likely to freeze, so that it may be lifted from the wall:—care should always be taken in back filling to slope the packed earth from the wall rather than towards it.

Mr. Colman said that in filling behind the masonry of N. Y. State canal locks, broken stone one foot in thickness had been placed between the wall and embankment.

A communication was submitted from a prominent Canadian engineer, in which he said: "In practice I have always made my walls heavier than theory demanded, on account of the severe operations of frost in this northern latitude, where it strikes from 3 to 4 ft. into the ground, and yet without giving a slope or 'frost' batter to the back of the wall where the frozen earth presses against it, our strongest walls could not stand.

"It has been my rule to make the base of the wall equal to $\frac{3}{4}$ its height, but this is for first-class masonry laid in hydraulic cement."

Mr. Constable, by experiment with the model, demonstrated that two walls of same area of section, one rectangular and the other with batter on the face of $\frac{2.2}{10\,10}$, were equally stable, and also that the saving in material by giving much batter, is but little. A wall battered on the back less than on the face, evidently is less economical than if all the batter was on the face.

Attention was called to the difference in resistance to crushing per square inch of section of stones 1 in. and $1\frac{1}{2}$ in. cube, as stated in Mr. C B. Richard's paper, recording "Experiments on the Resistance of Stones to Crushing," read before the Society January 8th last: thus white marble gave a mean resistance in the first of 5,812, and in the second of 8,294 lbs. per sq. in. of section. The question was raised, what relation was there between the size and the resistance of specimens, and whether tests upon blocks proportioned like those used in any particular work would better enable the engineer to determine how much the latter could withstand.

Tests of the strength of any material are of

greatest value when conducted under conditions most like those governing actual use. The difficulty of making such upon large specimens was pointed out, and a brief of testing machines was given.

It was proposed to take up the latter as a subject of discussion at a future meeting of the Society.

SCIENTIFIC AND MECHANICAL SOCIETY, MANCHESTER.—An ordinary meeting of this Society was held on Wednesday, the 8th January. The council invite papers for this session on the following subjects: "On the Nominal Horse Power of Steam Engines;" "On the Friction of Steam Engines, based, if possible, on Experimental Data;" On Factory Chimneys, their Sectional Area, Altitude, Draft, etc.;" "On the Relative Strength of Wrought-iron Structures, with Punched and Drilled Rivet Holes;" "On the Introduction of Steel in Structures as a Substitute for Wrought Iron." Six new members were balloted for and elected, and five others were proposed for ballot at the next meeting. Mr. F. Shepherd. M. E., a Vice-president, then read his paper "On Sectional Boilers." The essayist estimated the number of steam boilers in the United Kingdom at 100,000; and after enumerating the various designs and constructions of sectional boilers, he made special reference to the "Patent Cop-tube Boiler," which he illustrated by a full-size drawing of a tube, and a model of a boiler, the leading features of which may be briefly described thus: It consists of a number of vessels resembling in shape a "cop of mule yarn' inverted, each vessel being a boiler in itself, and of the following dimensions: height, 5 ft. 6 in.; diameter of cylindrical belt, 24 in., tapering to 5 in. at the base, and 3 in. at the top, with 9-in. flanges on top and bottom. These vessels are disposed diagonally in a quadruple row, connected at the top with a trunk pipe and side branches to draw off the steam, and at the bottom for the introduction of the feed and collection of sediment. Fittings and furnace are of the ordinary construction. A warm discussion followed, in which the chairman, Mr. Beeley, of Hyde, and other members of the Society took part, and during which the described boiler came in for a free criticism; some excellent features, however, were duly acknowledged. After Mr. Shepherd's reply, the thanks of the meeting were accorded him for the able paper, and also to Mr. Harman for his services in the chair. Mr. Harman, after the announcement that the next meeting would be held that day fortnight, the 22d inst., when a paper would be read "On the Effect of the Sudden Alteration of Form on the Strength of Materials," by Professor O. Reynolds, M. A., C. E., closed the meeting at 10 P. M.

At the third ordinary meeting of this society, which was held on Wednesday, the 22d January, at the Trevelyan Hotel, Mr. H. W. Harman, C. E., a vice-president, presiding over a numerous audience, Professor Osborne Reynolds. M. A., C. E., of Owen's College, a vice-president of the society, read an able and interesting paper "On the Strength of Materials, specially considering the Effects of Sudden Fluctuations in the Shape of Structures." The paper, which was very instructive and exhaustive, lasted about an hour; but owing to the fulness of the treatment of the subject there was not much of a discussion, in which Messrs. Shepherd, Simpson, J. G. Lynde, the chairman, and others, took part, and in the course of which some striking examples from actual practice in support of the author's statements were put forth. The usual vote of thanks to the professor and the chairman brought the meeting to a close at about half-past nine. The next meeting will be held on Wednesday, the 12th of February.

A meeting of this Society was held on Wednesday, the 12th February, Mr. J. Shepherd, M. E., in the chair. Several gentlemen were proposed as members to be balloted for at the next meeting A communication "On the Steam Jacket, its Advantages and Disadvantages, is it truly Economical?" by A. Hildebrandt, engineer, was read. The author said he made no apology in re-introducing this subject; it was time that this question should be settled, and there were no great difficulties in its way, it only wanted some one to make a few careful experiments, and it was his object to induce some one who had the opportunity to do so, or give another the chance of doing it. He had investigated the subject theoretically, disinterestedly, and unbiassed, in order to satisfy himself, and had come to the conclusion that the principle of the steam jacket was opposed to economy. He found the advantages to be the following: (1) It increased slightly the capacity of the cylinder by keeping the steam within dry. (2) There was greater immunity from breakdowns by preventing the accumulation of condensed water in the cylinder. The disadvantages were: (1) Waste of fuel. (2) Increased labor in its attendance. (3) Increased outlay of capital, amounting to about 20 per cent. There must, therefore, be the inevitable verdict of "Not economical." In the discussion that followed, opinions were often diametrically opposed. Mr. Allott, of the Fairbairn Engineering Company, said that even when they turned the steam from the jacket in an engine which they had working they found that they could not keep up the steam. Mr. Schaffield, who has charge of the machinery of a large manufacturing concern (Messrs. Melland & Coward), said he had made careful observations for several months past with an engine of steady load, and found that when he discontinued the use of the jacket he saved 10 per cent. of fuel.

YORKSHIRE ARCHITECTURAL SOCIETY.—The annual meeting of the Yorkshire Architectural Society was held on Jan. 9th, under the presidency of the Dean of York. The report stated that for the first time for several years the committee had to report the loss of many members by death or resignation, without any increase in numbers. The finances, however, were in a satisfactory condition, and there was a large balance in hand. Referring to what was said last year concerning the publication of *fac-similes* of ancient stained glass in the Minster, the committee had to regret that circumstances prevented its progress, so that nothing had been done, although they were very far from giving up the hope that ultimately some steps would be taken for the furtherance of the work. The report next referred to the excursion of the year to Barnard Castle, and the inspection of objects of antiquarian interest in the neighborhood, and concluded by a refer-

ence to the progress of the works connected with the restoration of the south transept of York Minster, which, under the able direction of Mr. Street, was being rapidly placed in a safe condition. The officers and committee were re-elected for the ensuing year, and W. D. Husband, Esq., and Mr. Bradley, Precentor's Court, were admitted members of the Society. The Rev. G. Ormsby, vicar of Fishlake, read an interesting paper on "Yorkshire Churches and Yorkshire Wills." The paper entered into a variety of details as to the bequests left to churches at York, Beverley, Ripon, Hull, and various other sacred fabrics in several parts of the three ridings, in the fourteenth, fifteenth, and sixteenth centuries, the bequests varying in amount, 1s., 3s. 4d., and 13s. 4d. being the sums most commonly left, but larger amounts in some cases had been bequeathed. The Rev. George Rowe, Principal of the York Diocesan Training College, read a paper on the West Window of St. Martin's Church, Coney street, York.

CIVIL AND MECHANICAL ENGINEERS' SOCIETY.—On Friday, February 7th, a paper was read by E. Perrett "On Various Kinds of Condensing Apparatus for Steam Engines." The writer gave a brief general description of condensing apparatus and steam engines, and then went on to describe more particularly the principal kinds of condensing apparatus used, or proposed to be used, up to the present time. Injection into the cylinder, injection into a separate condenser, surface condensation of water, surface condensation by air, and condensation by use of a central cone of water and an expanding delivery tube, were touched upon, and the advantages and disadvantages of the various systems reviewed. The writer in the course of his remarks pointed out that up to the present time no practical method of air condensation had been proposed, the enormous quantity of air required to effect this entailing such a consumption of power by the use of fans as to more than compensate for any advantages gained by a vacuum. As regards condensation by a central cone and induction tube, as exemplified by Morton's ejector-condenser, it was stated that under favorable circumstances, such as a liberal supply of condensing water with a slight head, and not warmer than 60 deg., by the use of this apparatus attached to the exhaust of a high-pressure engine about 30 per cent. of the fuel could be saved. It was pointed out that great similarity existed between this apparatus and the "blow through" condenser used by Dr. Alban, of Plau, nearly fifty years ago. The writer suggested in the latter part of his paper that an efficient air condensing apparatus for locomotives might be made by removing the water tank in an ordinary tender and replacing it by a faggot of vertical copper tubes to receive the exhaust steam, and exposing a surface of about 5,000 or 6,000 sq. ft., for which there was ample room on the tender. It was stated that this would probably be sufficient condensing surface for a locomotive having 1,000 ft. of heating surface, and it was anticipated that by providing proper channels amongst the tubes (aided, if necessary, by wind deflectors) a sufficient circulation of air would be kept up by the passage of the tender through the atmosphere. It was suggested that the loss of the blast might be advantageously compensated for by the use of a Siemens jet fed direct from the boiler. The numerous and apparent advantages of applying this method of condensation to locomotives were pointed out, such as the saving of 30 per cent. of the fuel, supplying the boiler with pure water, reduction in the weight of the boiler, and consequent reduction in the wear on the rails. A lengthened discussion followed the reading of the paper, in which the principal questions raised as regards the air condensing apparatus were, the difficulty likely to be experienced in making and keeping tight such a great number of joints, and also as to the quantity of power likely to be consumed by the entanglement of the air amongst the condenser tubes when the tender was moving at a high rate of speed. The proceedings terminated with a vote of thanks to Mr. Perrett for his paper. The paper was illustrated by a large number of diagrams which showed clearly the various methods of condensation referred to.

At a meeting of this Society on the 3d ult., Mr. W. Meakin read a paper "On the Preservation of Iron," in which he reviewed the various means adopted for the purpose, such as (1) the application of paints, cements, etc.; (2) the application of lacquers, oils, etc., and the enamelling processes; and (3) the protection gained by the metals, as galvanizing, plating, etc. The necessity of considering iron as a perishable material, and of taking every possible means of guarding it from unnoticed destruction, was strongly pointed by some examples of modern works in which corrosion appeared to be invited. The principles laid down as desirable were (1) to use the iron in the most compact masses possible; (2) to avoid all lodging-places for water, and to arrange for its draining off all parts as quickly as possible; and (3) to require every piece of ironwork to be completely secured by a protective covering before leaving the factory. The present maintenance of so much of the old ironwork was ascribed to the careful "facing" each part received on completion, by being brushed over with various drying oils, and exposed for a considerable time to the "thick smoke" of a wood fire. Thus was formed that "skin" on the iron which all practical men were so unwilling to disturb, though often from a mistaken idea of its superior strength; and this principle of forming a foundation-coat of a resinous or tarry nature, burnt on to the surface of the iron by a heat much greater than that to which it would be subsequently exposed, was strongly recommended for general re-adoption. A discussion followed, in which Messrs. G. Usill, C. Kingsford, E. Perrett, W. F. Butler, C. J. Samuda, E. H. Brewster, and the President (Mr. C. W. Whitaker) took part.

INSTITUTION OF MECHANICAL ENGINEERS.—The twenty-sixth anniversary meeting of the members of this institution was held on Thursday, the 23d January, in the lecture theatre of the Midland Institute, Birmingham; C. William Siemens, Esq., D. C. L., F. R. S., president, in the chair.

A paper was read giving a "Description of an Improved Apparatus for Working and Interlocking Railway Signals and Points," by Mr. William Baines, of Smethwick. The levers working the various signals and points at railway junctions and stations are now required to be arranged in such a manner as to be mutually interlocking by self-acting means, in order that safety may be

insured by rendering it impossible for any signal or point to be moved so as to allow any train to pass, unless all the necessary signals or points have been previously so placed as to insure safety by preventing the passage of any other train that could interfere with the first. This is effected either by locking the hand levers by means of some arrangement of self-acting catches—the mode that has previously been generally adopted—or by locking the detents that hold the levers in their respective positions; and the latter principle has the advantage that the movement of any lever cannot begin until its detent is unlocked, thus preventing the risk of the partial movement of the signal or point that is liable to take place from the springing and wear of the parts when the levers themselves are locked, the locking apparatus being then exposed to the whole strain of the pull on the lever: but when the detent is locked this strain is limited to the pressure of the fingers upon the detent handle. The latter principle is adopted in the improved apparatus described, in which the detent of each lever is locked by means of a sliding rod passing down from the detent, and carrying a projecting tappet at the bottom, which bears upon the arm of a rocker that turns freely upon a horizontal shaft fixed alongside the main shaft on which the levers are centred. This tappet is pressed down when the detent handle is moved to release the lever, and a second arm on the opposite side of the rocker is thereby pressed up under the corresponding tappet of the adjoining lever, so as to lock the detent of that lever, and prevent its release. The rocker shaft passes through a curved slot in the bottom of the first lever, and the rocker is held in its position whilst traversing the slot, so that the detent of the other lever continues securely locked until the first lever is brought back to its original position; the mere raising of the detent of the first lever is sufficient to effect this locking, and it can be effected in either the backward or forward positions of the levers. The mutual interlocking of the large number of levers required at a complicated junction is effected by an extension of this apparatus, having four of the rocker shafts, which have been nearly a year in regular work. In the case of a distant signal, worked by a pair of long wires from the signal box, the changes of length in the wires caused by their expansion or contraction, from changes of temperature, are prevented from interfering with the correct action of the signals, by means of a self-acting compensating apparatus, consisting of a shaft that has a radial movement horizontally, having its inner end carried in a bearing pivoted directly under the hand lever working the signal, and its outer end traverses along a curved guide rail. The inner end of the shaft has a lever connected to the hand lever working the signal, and the outer end carries a pulley, round which the pair of wires from the signal are fixed; and a suspended weight acting upon the end of the shaft, and pulling it in the opposite direction to the signal wires, keeps them always in uniform tension, whatever change of length may occur. When a single wire only is used for working the signal, a rack with a self-acting pawl is used to hold the shaft in its position whilst the lever is in action, the pawl being pressed down into the rack by the rotation of a cam upon the shaft. A working model of the locking and compensating apparatus was exhibited in action.

At the meeting of the Society of Telegraph Engineers, held a few days since, Mr. Latimer Clark read a communication from Mr. Willoughby Smith, the electrician of the Telegraph Construction and Maintenance Company, detailing a discovery which he had made of the extreme sensibility of selenium to the influence of light during the passage of an electric current. If the bar of selenium placed in the dark have an electric current passed through it, and it be subjected to the influence of light, either daylight or that of a lamp or candle, its power of conducting electricity is immediately doubled, and the effect ceases as soon as the light is withdrawn. Its effect is not at all diminished by the intervention of rock salt or colored glasses, and is in no way due to the effect of heat. Mr. Clark pointed out the value this discovery would have in connection with photo-metric measurement.

IRON AND STEEL NOTES.

Dephosphorizing Iron in Puddling.—Dr. T. Scheerer has brought before the public a new process for separating phosphorus from the iron during the operation of puddling, using the chlorides of calcium and sodium; and although we have not as yet received details of the mode of working, it is said that the results obtained have proved that a very good and fibrous bar could be obtained from pig iron containing phosphorus which, in the ordinary system of puddling, was unfit for making bar iron. The amount of chlorides to be added in puddling depends upon the amount of phosphorus in the pig, and is given at three times the weight of the phosphorus to be removed.

Iron in Blast-furnace Slags.—It frequently happens that the iron chemically combined in blast-furnace slags is by no means insignificant in amount, and it therefore becomes interesting to know from time to time what that amount is.

It is, however, very difficult, and sometimes impossible to decompose these slags by means of acids. This is particulary the case with crystalline slags, the vitreous slags being much more decomposable.

A portion of finely-pulverized vitreous slag, treated with hydrochloric acid, is dissolved, leaving a silicious jelly, but the crystalline portion is scarcely affected. It is recommended that ammonium fluoride be employed to decompose the slags, as it can be prepared and kept without difficulty.

The finely-pulverized sample is heated in a platinum crucible on the water bath, with three to four times its weight of ammonium fluoride. Sulphuric acid is gradually added, the heat being continued until an appearance of ebullition ceases. The crucible is then heated on the sand-bath until the acid begins to volatilize. Cold water is now added, when everything must dissolve but the calcium sulphate. The precipitate is thrown on the filter and washed, till the washing water no longer contains iron. The filtrate is treated with

zinc in a retort, to reduce the iron, which is determined in the solution in the usual way by potassium permanganate.

RAILWAY NOTES.

THE WEAR OF IRON RAILS.—The iron rails first used upon English railroads stood from fifteen to twenty years, even under an enormous traffic; no such rails are now made, unless of steel. In 1840, it was estimated, upon the London and North-Western Railway, that the passage of 313,000 trains would wear out a 70-lb. rail. With the present material put into rails, no such service is obtained. Mr. Price Williams states that the best quality of rails, as now made, will not stand the passage of over 100,000 trains. The difficulty does not seem to be so much in the impossibility of making good and serviceable iron rails as in the fact that few are made. In this respect the same facts hold good, as has been frequently referred to in the manufacture, during late years, of nearly all classes of iron work.

With regard to the life of steel rails, everything here again depends upon the quality of the metal. A pair of 21-ft. Bessemer steel rails, upon the London and North-Western Railway, outlasted sixteen faces of iron rails, being evenly worn to a depth of a little over a quarter of an inch, having in about three years sustained the traffic of upwards of 500,000 trains. This particular pair of rails was finally destroyed by a locomotive running off the track, the wheels striking the rails transversely and badly bending and breaking them. It was estimated that they would have endured at least one-half as much more traffic but for the accident.

So, too, upon the Philadelphia, Wilmington, and Baltimore Railway, a good steel rail has outlasted sixteen iron rails, the use of both being the same, and on many other roads of large traffic the same successful results have been achieved. Railway managers must exercise more care and discrimination in the quality of the rails they purchase, whether made of iron or steel. In fact, there is a large qantity of miserable stuff sold for steel rails, as many managers know to their cost. Under favorable conditions, *good iron* will last eight years under the average traffic of a first-class road, but with the material commonly employed, from three to six years, and sometimes less, is all that can be counted upon. Quick trains wear out rails much more rapidly than slow trains; the difference is estimated as two to one. The wear is greatest where the bulk of the traffic falls upon the down grades. In one instance, a mixed traffic of 62,390 trains very nearly wore out the best rails on a 40-ft. descending grade in seven and a half years, while the same description of rails upon a level grade, withstood the passage of 203,122 trains. For equal amounts of traffic the wear of rails is assumed to be as the square of the speed.

ENGINEERING STRUCTURES.

THE BRIDGE AT ST. LOUIS.—We take the following from the St. Louis "Dispatch," regarding the present condition of the St. Louis Bridge:—

At present the engineers are progressing with the work of placing large hydraulic jacks in the tops of the piers and abutments preparatory to finishing the work. These will be of immense power, each calculated to raise thousands of tons. They will be used—so soon as the weather moderates—to raise strongly built wooden towers upon which the chains that support the arch cords are to rest while being put together. These chains are perfect curiosities in their way, and for strength and size are far superior to anything of the kind ever heard of. The links are composed of ¼ in. iron, 6 in. wide and 35 ft. long. There will be five stands of these to each chain, which will be made of sufficient length to admit of their being extended over the wooden towers referred to, and about 100 ft. on each side. The idea is to use them for a purpose similar to that for which hog-chains are employed in the construction of boats, the great difference being that they can stand a tension equal to the hog-chains of all the steamers on the Mississippi. The arch cords referred to will be composed of staved tubes hooped like barrels, made of steel and in twelve feet lengths. There will be 1,012 of these, 900 of which have been completed, and as the Keystone Bridge Company is manufacturing at the rate of 200 per month, this, the most important and largest part of the superstructure, will be completed in a few weeks. These tubes are perfectly straight, the arching being accomplished by turning a very slight bow in the side ends. They will fit together perfectly, and at the junctions will be secured by strong cast steel hammered clamps, with s ats cut in the inside to correspond with a series of turned collars on the tubes. The two parts of the clamp will be drawn together, and the collar squeezed home by means of a large steel key and temporary appliances to each, running through corresponding orifices made in both. To these pins a hammered charcoal iron bar, 12 in. wide and 1 in. thick, will be fastened on each side and will thus connect the upper and lower pipe-cords, which are 12 ft. apart. Such is the perfection with which this work was calculated and done, that were either the bevelling of the tubes or the turning of the slats and collars but a thousandth part of an inch wrong it would throw the arch several inches out of place only 12 ft. from the defective point. Indeed, the entire cord will, when finished, be as precise as the machinery of a clock.

There is every reason to believe that everything connected with it will move along smoothly when work is assumed in force, and that by the 1st day of July locomotives will be merrily whistling down brakes as they come near the East St. Louis approach, preparatory to crossing. In anticipation of this much wished-for event, it is proposed to let the contract for the erection of the East St. Louis approach on Wednesday next; and as the structure will be composed entirely of trestle and iron, competent engineers state that three months will be ample time to complete it.

NEW BRIDGE OVER THE THAMES.—A project has been brought forward for the construction of a new bridge below London Bridge, over the Thames, in the neighborhood of the Tower; and the sanction of the Legislature is to be sought in the ensuing session; of the success of which attempt considerable doubts may not unnaturally be entertained. The character of the

bridge, in point of engineering and structural details, is peculiar and unusual. Inasmuch as vessels of large tonnage come up to London Bridge, the proposed structure would impede the navigation of the river unless provision were made for such vessels passing through. The bridge is to consist of five spans, the centre span to be 400 ft. wide, with two other spans at either end, 90 and 70 ft. wide respectively. The 90-ft. spans on each side of the river will be so constructed as to admit of being opened for the passage of large vessels. The opening of these spans is to be effected by underground machinery and hydraulic power, and their width will admit of vessels of the greatest beam passing through; while the altitude of the central span, upwards of 29 ft. clear above the high-water mark, will be sufficient to admit of vessels of a smaller tonnage passing under it. Carriage traffic generally will thus be stopped whenever one of the spans is open, but the structure is so designed that there will be no obstruction or delay in pedestrian traffic, which will be continuously secured by spiral staircases within the piers supporting each of the opening spans, communication between the staircases being effected by means of tunnels under the bed of the river, which will form submarine footways. The entire length of the proposed bridge from shore to shore will be upwards of 800 ft. and the gradient 1 in 35. We are not aware that, even in the boldest days of railway projects, so fruitful in fruitless schemes, anything like the above was ever before hazarded.

THE BATTERY, NEW YORK.—In connection with this favorite New York resort, it may be noted that a new pier is being constructed. The new pier will be 500 ft. long and 80 ft. wide, and it will be supported on 19 arches. These are placed upon foundations of huge blocks of artificial stone.

ORDNANCE AND NAVAL.

NEW TELEGRAPHIC BATTERY FOR MILITARY PURPOSES.—M. H. Cauderay, of Lausanne, describes the construction of a small, portable, and economical galvanic battery, which, he says, will be particularly useful for purposes of military telegraphy. Its fundamental part will certainly be peculiarly accessible to military men, for the cells, which serve at the same time as the positive electromotors, consist of the used copper cases of rifle cartridges. These are scraped clean, and arranged in holes made in a small board. They are then charged with a layer of about half an inch of pounded and moistened sulphate of copper, and filled up nearly to the top with sawdust soaked in pure water. The negative electromotor is a small cylinder of zinc, about an eighth of an inch thick, which is passed down into the sawdust through a hole in a varnished cork, closing the aperture of the cell. A small notch must be made in one side of the cork to allow of the escape of gas. Of course the copper cell and the zinc cylinder must have wires attached to them, for the purpose of attaching them to the opposite poles of the neighboring cells. A battery of 20 such cells, exhibited by M. Cauderay to the Society of Sciences at Lausanne, sufficed to work a portable military telegraph against a resistance of 4,000 Siemens units. The knowledge of so cheap a form of battery will be welcome to many who like to amuse themselves with experiments in galvanism.—*Globe.*

SIEBE, GORMAN, AND CHRISTY'S PATENT SHIP-RAISING STEAMER.—In our impression of the 9th February, 1872, we published a drawing and description of a ship-raising pontoon, patented by Messrs. Siebe, Gorman, and Christy. Public attention having been called by recent disasters to the necessity for some speedy means of raising vessels and cargoes, a number of leading men interested in shipping, have satisfied themselves of the practicability of this invention, and we are informed that it has been determined at once to form an association for the purpose of constructing a steam vessel capable of raising ships with their cargoes weighing up to 5,000 tons. The vessel will be so constructed as to stand any weather; she will have separate engines of 200-horse power each, driving four screw propellers, and attaining great speed. The engines will work the windlasses as well as the centrifugal pumps. It is proposed that a pair of gates should be fitted at the stern of the vessel to form a perfect caisson (the mud on shore forming a bottom) round any wreck sunk in rivers or other shallow waters, and the vessel will be supplied with four of J. and H. Gwynne's centrifugal pumps, each throwing 10,000 gallons of water per minute. Thus, when the tide falls, the caisson and the wreck could be kept sufficiently dry to enable any leak or damage to be temporarily repaired, and both wreck and pontoon steamer would rise with the tide and at once proceed to a place of safety.

A RIVAL TO THE BESSEMER SHIP.—The St. Petersburg correspondent of the "Morning Post," writes:—"The famous Bessemer ship has just encountered an unexpected rival in the floating cabin devised by M. Alexandrovski, the inventor of the 'under-water vessel.' The construction is very much the same as that of the Bessemer, but the cabin, instead of being attached to a pivot, literally floats in a kind of tank placed amidships between the engines. The invention was tested a few days since by the Grand Duke Constantine, in his capacity as head of the Naval Department, with a perfectly satisfactory result, all efforts to shake the cabin proving utterly unsuccessful, and the pitching as well as the rolling motion of the vessel being completely counteracted. M. Alexandrovski leaves for England within a few days, in order to patent his invention, intending to visit France a little later with the same object."

THE IRON STEAMER COLON.—This beautiful steamer, the launch of which from the works of the Delaware River Ship-Building and Engine Works, Chester, Pa., in November, last, we duly noticed, can be now seen at the foot of Ninth street, East River (Morgan Iron Works). She has been brought here to receive her engines and boilers, and finishing touches. Those interested in the advancement of our ship-building interests should not fail to visit this noble craft, and be further satisfied that we *can* build ships in America.

The Colon is a propeller, with a straight bow, elliptical stern, clean run, and beautiful lines. Her dimensions are: Length, 303 ft.; beam, 40

ft.; depth of hold, 30 ft. 6 in., and gross tonnage, 2,324. She is fitted up with five water-tight bulkheads, is brig-rigged, carries eight metallic lifeboats, is amply supplied with hose and fire apparatus. Her saloons and cabins are very handsomely fitted, the joiner work being of highly-polished rose and satin woods. The engines which are about to be placed in her have been constructed abroad. They are of the compound type, with two inverted cylinders placed side by side, with the cranks at right angles. These cylinders are respectively 88 and 50 in. in diameter, the stroke of the piston in each being 2 ft. 6 in. Her motive power is capable of working up to 2,000 horse. Her propeller has four removal blades, is 16 ft. 6 in. diameter, and has 36 ft. pitch. She has four boilers, the shells of which are 13 ft. diameter and 18 ft. 6 in. long, with three furnaces in each.

The mate to the Colon, to be called the Colima, is to be launched shortly. It is intended that these vessels shall be patterns of American enterprise in ship-building.

BOOK NOTICES.

THE DEPTHS OF THE SEA. By C. WYVILLE THOMSON, LL. D., F. R. S. London: Macmillan & Co. For sale by Van Nostrand.

This beautiful work is a record of the recent discoveries in a fresh field of scientific research. It will doubtless be received as would the journal of a traveller in a region never before reached by explorers.

The fact of the existence of animal life at great depths, now definitely proven, is of the deepest interest. The list of species or of genera even recently found at depths exceeding 2,000 fathoms, is by no means a short one.

The author says: "The remarkable general result that even to these great depths the fauna is varied and rich in all the marine invertebrate groups, has inundated us with new material, which, in several of the larger departments, it will take years of the specialists to work up."

The fullest possible description is given of the construction and use of the apparatus employed.

The chapters on Deep Sea Temperatures, the Gulf Stream, and the Continuity of the Chalk, contain matter of the most absorbing interest. The colored charts are good, and the wood-cuts are of the highest order of excellence.

COLLINS' ELEMENTARY SCIENCE SERIES.—Elementary Mathematics, by LEWIS SERGEANT, B. A.; Theoretical Mechanics, by WM. ROSSITER, F. R. A. S.; Applied Mechanics, by WM. ROSSITER, F. R. A. S.; Land and Marine Engines, by HENRY EVERS, LL. D.; Navigation, by HENRY EVERS, LL. D.; First Book of Mineralogy, by J. H. COLLINS, F. G. S. London and Glasgow: Wm. Collins, Sons & Co. For sale by Van Nostrand.

This series of handy books is designed to furnish aid to students who, from some necessity, must confine their labors to a brief outline of the several branches of scientific study. The authors are all professional instructors, and have evidently labored to produce works worthy of experienced teachers.

Each work contains about 150 pages and presents the topics in rather more rudimentary form than the famous Weale series.

The Elementary Science Series (27 vols. in all) is already supplemented by the "Advanced Science Series," presenting all the scientific subjects pursued in the technical schools. Each volume contains about 350 pages, with numerous illustrations.

A PRACTICAL TREATISE ON THE MOVEMENT OF SLIDE VALVES BY ECCENTRICS. By C. N. MCCORD, A. M. New York: D. Van Nostrand.

The author of this new work is the Professor of Mechanical Drawing at the Stevens Institute of Technology, and is therefore presumably familiar with the wants of learners, as well as with the logical methods whereby such wants are satisfied without unnecessary vexation of spirit.

An examination of the proof-sheets before us convinces us that learners beyond the reach of the Professor's voice will have occasion to thank him for writing a book. We heartily commend the following remarks from the author's preface to the reader's consideration:

"The action of the slide valve of the steam engine, operated through various intervening devices by a motion derived from an eccentric, has been so often and so ably discussed, that in presenting a new treatise on the subject, an explanation seems called for, offering an excuse for its appearance. The object of the present work is that of aiding practical engineers in forming a clear idea of, first, the nature of the motion, and what the valve *can* be made to do; second, the requirements of the engine, and what the valve *must* be made to do; and, third, the construction of the movement, and how to make the valve do what it is to do. And the plea for its existence, upon which main reliance is placed, rests primarily on the manner in which these questions are presented.

"Much labor and zeal have been expended, not to say wasted, in treating this matter analytically, the method being to embody the elements, constant and variable, of the whole combination, including all the connecting rods, cranks, eccentrics, rock shafts, links, and levers, making up the working gear interposed between the piston and the valve, in an equation expressing the movement as influenced by them all; and by discussing this equation to deduce results as affected by various supposed changes in the proportions or relations of these elements.

"The subject affords a good field for the display of analytical acumen; and this method of employing algebraic skill for a practical purpose is at once elegant and refined; but such investigations do not answer the purposes above set forth; admirable as they may be intrinsically, they are so mainly to the select few as interesting studies of applied mathematics.

"It must be borne in mind that of those who study closely the mechanical movements of the steam engine, particularly those who are directly interested in the practical matter of engine building—the draughtsmen who design as well as the mechanics who execute—the great majority are not versed in the higher mathematical branches. And more especially is it true that they are seldom of the order of mind which turns naturally to analysis as a mode of solving problems; the

geometrical reasoners are the ones most likely to adopt a profession in which graphic methods are in constant use, and to many, proficient in these, any thing written in the language of symbols is a sealed book, while to many more it is a very dry one.

"Again, the connection between an abstract formula and its concrete embodiment is so indirect and obscure, that even those competent to trace the equation through its various transformations from the initial to the final stage, have frequent need to resort to graphic means of illustrating their progress, and are absolutely driven back to them in order to construct their ultimate expressions, and reduce their theoretical deductions to a practical form.

"It is to be considered, too, that the engine itself is not a creature of analytical instincts; its parts move with geometrical precision, in lines and about centres which, having fixed linear relations to each other, are just as susceptible of accurate delineation on paper as of accurate adjustment in metal; they did so before their motions were analyzed, and would continue to do so to the end of time, though the art of analysis were forgotten. In fact, the mathematical education of the engine has never gone beyond geometry; it was planned by geometry, it was built by geometry, and it runs by geometry. To be sure, you may examine it analytically, and formulate the results; but, algebra or no algebra, it will answer no questions which it cannot answer by geometry.

"Since, then, the valve movements must eventually be constructed by graphic processes, whether they be previously discussed analytically or not, there seems to be no good reason why the former method should not be separately used in the whole investigation."

"On the contrary, it would appear from the preceding considerations that it is peculiarly adapted, not only to the elucidation of this subject, but to the tastes of those specially addressed; it has, therefore, been adopted, to the entire exclusion of algebraic analysis, which those who prefer it may find exhaustively used in other works.

"In regard to the general arrangement and subdivision of the matter presented, it is proper to remark, that, in the author's opinion, the chief source of the difficulty often found in imparting, even by the graphic method, a thorough insight into the action of the slide valve, and the construction of its movement, is to be found in the fact that usually the investigation starts out with the three ported or common slide, very often miscalled 'the simplest form of the valve;' and introduces at once the several adjuncts of 'lap,' 'lead,' 'inside clearance,' etc., which, though simple enough when separately considered, are bewildering to the beginner when he is at once confronted with them all.

"By dissecting this valve, and considering its members and their functions one by one, the author has endeavored to make their combined action more readily comprehended."

The separate chapters bear titles as follows, viz.:

1. General Investigation of the Eccentric Motion.
2. Action of the valve as applied to a single steam port.
3. Action of the exhaust valve of the three-ported or common slide valve, and of the two-ported or box valve.
4. Independent or cut-off valves.
5. The angular vibrations of the main connecting rod and the eccentric rod.

The book is a handsome 4to and illustrated with 85 copperplate figures, making 8 full-page plates.

THE THEORY OF STRAINS IN GIRDERS AND SIMILAR STRUCTURES; WITH OBSERVATIONS ON THE APPLICATION OF THEORY TO PRACTICE, AND TABLES OF THE STRENGTH AND OTHER PROPERTIES OF MATERIALS. By B. A. STONEY, M. A., M. Inst. C. E., etc. New York: D. Van Nostrand.

This handsome volume of 664 pages in large octavo, is slightly misnamed in its leading title, "The Theory of Strains in Girders," as if the word *theory* were equivalent to laws and demonstrated results. The great and characteristic merit of this work is that it is eminently practical. Where theories, and even hypotheses, are sparsely stated, these are referred to their respective authors; and in all cases in which there is a disagreement, either in theory or in fact, the author maintains a perfectly neutral and impartial position. Indeed, this work is a perfect cyclopædia of all matters—practical and mathematical—of ironwork applied to engineering. The work is full of formulæ and tables, establishing means of reference in all difficult problems, and sources of information in every possible department of engineering.

There are five plates and 123 wood-cuts illustrating the action of weights and strains acting on girders under various conditions, such as when loaded at one or both ends, loaded uniformly or at the middle, loaded at irregular or measured intervals, and when traversed by the weight of trains. The various chapters contain the latest results referring to flanged girders with braced or thin continuous webs; the action of transverse strains and of weights on girders of various sections; braced girders with parallel flanges and webs formed of isosceles bracing; girders with parallel flanges connected by vertical and diagonal bracing; and braced girders with oblique or curved flanges. The remainder of the first half of the volume treats of deflection, continuous girders, quantity of material in braced girders, the angle of economy, torsion, strength of hollow cylinders and spheres and pillars of various forms and materials. Thereafter we have a minute account of the tensile strength, under various conditions, of cast-iron, wrought-iron, iron-wire, steel, steel-wire, bronze, alloys of copper and tin, timber, building material, cordage, chains and wire-rope. The shearing-strain and elasticity and set in these materials. Then follows a perfectly exhaustive array of facts respecting temperature as affecting materials, flanges, webs, cross-bracing, cross-girders and platform, counter-bracing, deflection, and camber, depth of girders and arches, connections of various materials, estimation of girder work, with a dozen examples and limits of the length of girders.

The Appendix, which occupies 28 pages, is statistical matter on the weights and strains affecting the Boyne Lattice Bridge, Newark Dyke Bridge, Chepstow Bridge, Crumlin Viaduct, Bowstring Bridges, Charing Cross Bridge, the Conway and Brotherton Plate Tubular Bridges, and an elaborate set of tables of the size and weight of various materials. The special advantages of the present work are, that it has had, as a second

edition, a careful revision and correction by the author, the experienced engineer to the Dublin Port and Docks Board; and that the vast amount of statistical matter, whether given as the result of experiment or calculation, is in every case referred by a foot-note to the authority from whom it is taken. Thus the reader who is interested in any particular set of facts is enabled to pursue his inquiries in the writings of experimentalists, physicists, and in the valuable transactions of engineering and scientific societies.

Mr. Stoney tells us that the chapters in this book have been written for the purpose of supplying what has long been a want in engineering literature - a handbook on the theory of strains, and the strength of materials. Writers on mechanics have treated on the theory of transverse strains, but their remarks have been confined to strains on plain girders, or to the simplest forms of trussing, of little practical use.

Mr. Stoney's work, by sheer force of merit, and as a complete storehouse of information, will find its way wherever iron is used, and wherever the English language is understood.

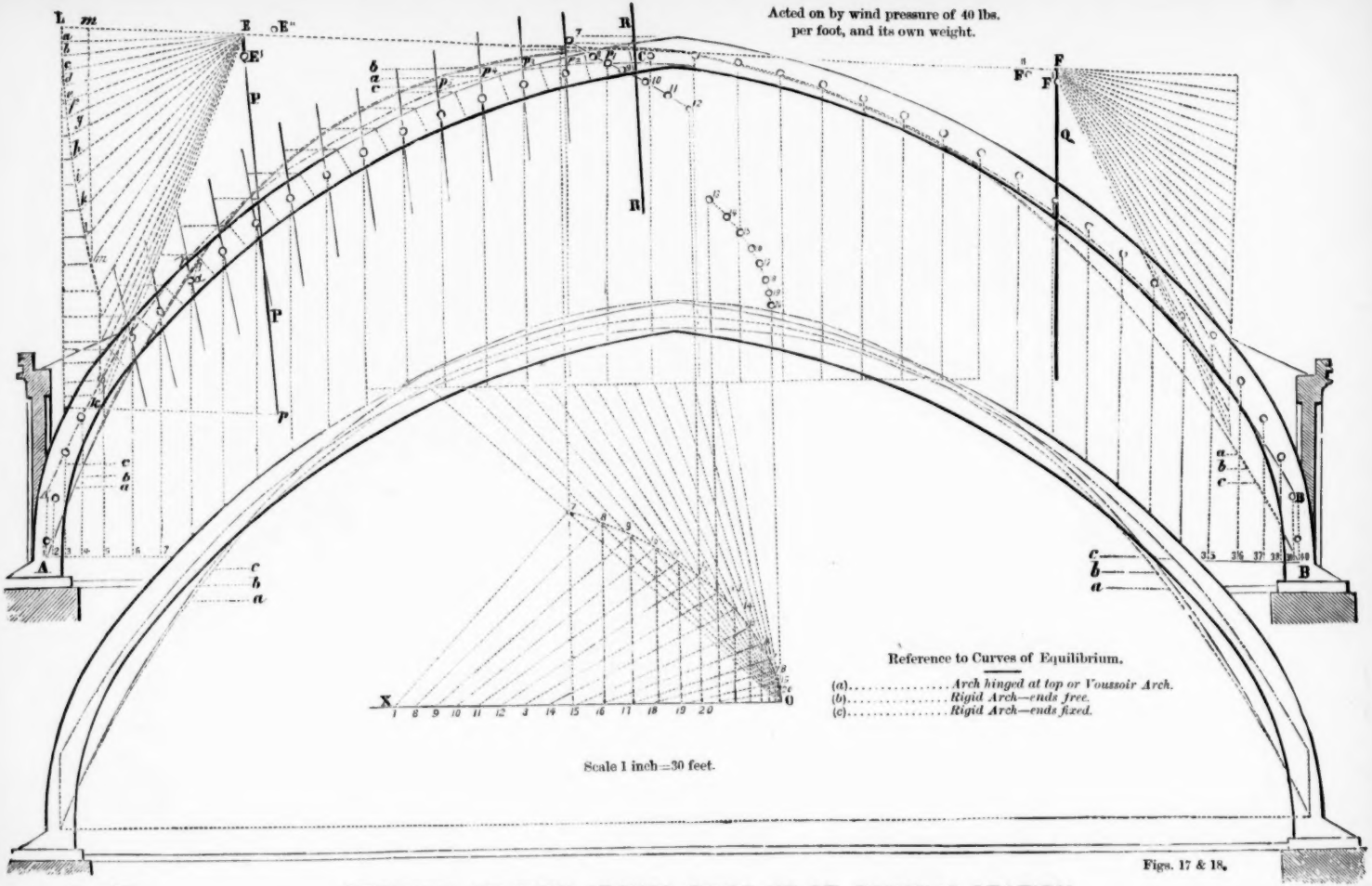
MINERAL PHOSPHATES AND PURE FERTILIZERS. By CAMPBELL MORFIT, M. D., F. C. S. New York: D. Van Nostrand.

The date of the patent taken out by Mr. Lawes, in 1842, for treating mineral phosphates with sulphuric acid, has proved the date of the commencement of a new industry which has now attained to vast proportions. At present the manufacture of super-phosphates in Great Britain can hardly be short of 400,000 tons per annum, and the market value of the same cannot be under £2,400,000. Comp tition naturally tends to develop improvements, and of late years several novel processes have been suggested for the better treatment of mineral phosphates. Dr. Morfit's book is mainly devoted to a description of these new methods, and more especially to a detailed account of the practical working of his own inventions. Dr. Morfit's plan is to roast the powdered crude calcium phosphate, then dissolve it in strong hydrochloric acid, and precipitate the solution by ammonia gas, by lime, by whiting, or by the addition of a previously precipitated mixture of the oxides and phosphates of iron and aluminium. When the solution is left acid by an insufficient use of lime, or when the last two precipitants are employed, the precipitate obtained consists chiefly of dicalcic phosphate. The resulting calcium phosphate is either sold as such, or else converted into a superphosphate. The acid mother liquors are precipitated with lime, which throws down the iron, aluminium, and remaining phosphoric acid; the purified calcium chloride is then boiled down and brought into a solid state for sale. There is thus a constant production of two bye-products. The author regards them as valuable materials; the calcium chloride is to be used for making Ransome's artificial stone, and the ferruginous phosphates for the clarification of sewage. This scheme looks promising on paper, but must require special local circumstances for its fulfilment.

The reader will find in this book a full account of the patents of Way, Spence, Townsend and others, who have worked on the subject, together with much practical information as to the construction of apparatus and the performance of manufacturing operations; the subject is, in short, fully treated. The book contains, however, some very unpractical schemes, as when the author proposes the universal adoption of earth closets, with the recovery of the nitrogen by combustion with soda-lime, and the production of phosphoric acid by lixiviation of the residue. Now as fully saturated closet earth contains, according to Voelcker, but .33 per cent. of nitrogen, and .55 per cent. of phosphoric acid more than the loam originally taken, the notion seems to us somewhat impracticable.—*Nature.*

MISCELLANEOUS.

SOLDERING IRON AND STEEL.—For large and heavy pieces of iron and steel, copper or brass is used. The surfaces to be united are first filed off, in order that they may be clean. Then they are bound together with steel, and upon the joint a thin strip of sheet copper or brass is laid, or, if necessary, fastened to it with a wire. The part to be soldered is now covered with a paste of clay, free from sand, to the thickness of one inch, the coating being applied to the width of a hand on each side of the piece. It is then laid near a fire, so that the clay may dry slowly. The part to be soldered is then held before the blast, and heated to a white heat, whereby the clay vitrifies. If iron is soldered to iron, the piece must be cooled off in water. In soldering steel to steel, however, the piece is allowed to cool slowly. The semi-vitrified clay is then knocked off, and the surface is cleaned in a proper manner. By following the hints given, it will be found that a durable and clean soldering is obtained. If brass, instead of copper, is used, it is not necessary to heat so strongly; the former recommends itself, therefore, for steel. Articles of iron and steel of medium size are best united with hard or soft brass solder. In both cases the seams are cleanly filed and spread over with the solder and borax, when the soldering seam is heated. Hard brass solder is prepared by melting in a crucible eight parts of brass, and adding one part of previously heated zinc. The crucible is then covered and exposed to a glowing heat for a few minutes, then emptied into a pail with cold water, the water being strongly agitated with a broom. Thus the metal is obtained in small grains or granules. Soft brass solder is obtained by melting together six parts of brass, one of zinc, and one of tin. The granulation is carried out as indicated above. Small articles are best soldered with hard silver solder or soft solder. The former is obtained by alloying equal parts of fine silver and soft brass. In fusing, the mass is covered with borax, and, when cold, the metal is beaten out to a thin sheet, of which a sufficiently large and previously annealed piece is placed with borax upon the seams to be united and heated. Soft silver solder differs from hard silver solder only in that the former contains one-sixteenth of tin, which is added to it during fusion. Very fine articles of iron and steel are soldered with gold, viz., either with pure gold or hard gold solder. The latter can be obtained by fusion of one part gold, two parts silver, and three copper. Fine steel wire can also be soldered with tin, but the work is not very durable. Hard and soft brass solder are used for uniting copper and brass to iron and steel, silver solder for silver, hard gold solder for gold.


Acted on by wind pressure of 40 lbs.
per foot, and its own weight.
Reference to Curves of Equilibrium.
(a)..... Arch hinged at top or Voussoir Arch.
(b)..... Rigid Arch—ends free.
(c)..... Rigid Arch—ends fixed.
Scale 1 inch=30 feet.

Figs. 17 & 18.

STRESSES OF RIGID ARCHES—ROOF OF ST. PANCRAS STATION.